ASIANA AIRLINES

Accident Investigation Submission

NTSB Accident File: DCA13MA120
Operator: Asiana Airlines
Model: Boeing 777-200ER
Aircraft Number: HL7742

Date of Accident:	July 6, 2013
Location of Accident:	San Francisco International Airport (SFO) San Francisco, California
Date of Submission:	March 17, 2014
Prepared By:	Asiana Airlines Inc.

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INTRODUCTION

On July 6, 2013, Asiana Airlines flight 214 crashed short of the runway at San Francisco International Airport following a rapid deterioration in airspeed below 500 feet. The record shows that there were complex and interrelated causes of this accident. These include that the flight crew, composed of three highly trained and experienced pilots, did not ensure a minimum safe airspeed during the final phase of approach; there were inconsistencies in the aircraft's automation logic that led to the unexpected disabling of airspeed protection without adequate warning to the flight crew; the low airspeed alerting system did not provide adequate time for recovery; and air traffic control instructions and procedures led to an excessive pilot workload during the final approach.

The pilots in the cockpit at the time of the accident were Captain Lee Kang Kuk (the "PF"), Captain Lee Jung Min (the "PM"), and First Officer Bong Dong Won (the "FO"). On final approach, the PF disconnected the autopilot and expected the autothrottle system to maintain the target airspeed of 137 knots. But the autothrottle, which had entered HOLD mode, had effectively, and surprisingly, turned off, thereby disabling airspeed protection. By the time a quadruple chime sounded to indicate low airspeed -- at 120 feet above ground level and less than 11 seconds prior to impact -- there was not enough time for the engines to spool up from idle, and, although the pilots quickly initiated a go-around, the plane struck the seawall.

Asiana has flown into SFO uneventfully for over 20 years, and Asiana crews have successfully accomplished high-energy, visual approaches to the airport numerous times. The series of events that led to the accident, involving an advanced technology aircraft flown by a highly trained and experienced flight crew, would have been difficult to predict given the qualifications of the pilots and Asiana's premier flight safety program.

1. FACTUAL INFORMATION

1.1 History of Flight

On July 6, 2013 at 11:28 a.m. Pacific Daylight Time, a Boeing 777 operated by Asiana Airlines as flight 214 and registration HL7742, crashed short of runway 28L at San Francisco International Airport ("SFO"). The flight was a regularly scheduled passenger flight from Incheon International Airport, Seoul, South Korea, and was operated under the provisions of 14 Code of Federal Regulations Part 129. Three persons, out of a total of 307 on board, suffered fatal injuries, while a number of others were injured, including three members of the flight crew.[1]

The flight was an operating experience ("OE") training flight for the PF, an experienced pilot who was in the process of transitioning to the B777 at the time of the accident. The PM during the flight was a B777 instructor pilot at Asiana, and the FO was an experienced B777 first officer; the FO occupied the cockpit jumpseat during the approach and landing.

[1] Survival Factors Group Factual Report, Addendum 2 at 4.

1.2 Personnel Information

1.2.1 The Pilot Flying (PF)

The PF, age 45, was hired by Asiana in 1994 after completing initial training at FlightSafety International in Vero Beach, Florida.[2] Prior to being selected to transition to the B777, he had served as a first officer on the B737 and B747, and as a captain on the B737 and A320. Additionally, he had been an A320 ground school instructor, as well as an A320 simulator instructor and OE instructor pilot.[3] At the time of the accident the PF had approximately 9,684 total flight hours, with 3,729 flight hours as pilot-in-command. He had flown into SFO 29 times as a first officer on the B747, handling four landings.[4]

The PF began his B777 transition training on March 25, 2013. During both the ground school and simulator phases of this transition training, he received specific instruction on the high-energy approach to SFO. In April 2013, two of his ground school instructors provided detailed training on the approach to runway 28L at San Francisco, including that they had discovered, through personal experience, that the B777's autothrottle may enter HOLD mode and not wake up when descending using the FLCH autopilot mode.[5] Additionally, training records indicate that the PF performed a visual approach six times during the simulator stage of his transition training in 2013, receiving a grade of "good" -- the best possible grade -- each time.[6] In May 2013, the PF successfully completed B777 certification training. Prior to the accident, he had completed eight legs of OE training flights and his training progress was described as "normal" and "going well."[7]

The PF suffered a broken rib and sprains of the cervical and lumbar regions of his spine in the accident.[8] These injuries were classified as "serious" by the NTSB,[9] but the PF did not receive medical attention until returning to South Korea where he was hospitalized from July 14-22, 2013.[10]

1.2.2 The Pilot Monitoring (PM)

The PM, age 49, was hired by Asiana in 1996. He had previously served in the Korean Air Force, where he flew the Phantom F4/RF-4C.[11] He was initially qualified as a B767 first

[2] Hr'g Ex. 2-A, Operations Group Factual Report at 8.

[3] *Id.*

[4] *See id.* at 11-12.

[5] *See* Hr'g Ex. 2-D, Statements of Capt. Kim Je Youl and Capt. Jung Tai Soo, and attachments thereto.

[6] *See* Hr'g Ex. 2-T, PF's B777 Simulator Training Record at *3, *17, *25, *27, *29, *31.

[7] Hr'g Ex. 2-B, NTSB Interview Summaries at 48, Interview of Capt. Lee Sung Kil, Asiana B777 Chief Pilot.

[8] Appendix A, Ex. 1, Flight Crew Medical Records at *2.

[9] *See* Survival Factors Group Factual Report, Addendum 2, Attach. 1 at 21.

[10] Appendix A, Ex. 1, Flight Crew Medical Records at *2.

[11] Hr'g Ex. 2-A, Operations Group Factual Report at 12.

officer and subsequently upgraded to captain on the B767. He transitioned to B777 captain in January 2008. He underwent B777 instructor pilot training in May and June 2013, and became qualified as a B777 instructor pilot on June 12, 2013.[12] He also previously served as an instructor pilot in the Korean Air Force, logging 380 flight hours as an instructor on the Phantom F4.[13]

The PM had 12,307 total flight hours, with 9,045 hours as pilot-in-command. He had a total of 3,208 hours in the B777. The accident flight was his first flight as a B777 instructor. As a B777 captain, he had made 17 previous landings at SFO, with the most recent taking place on May 8, 2013.[14] A review of the PM's records showed no significant deficiencies, with typical comments noting "good performance" or "very good performance."[15] The records also indicate that the PM performed a visual approach three times during the simulator stage of his instructor pilot training in 2013, receiving the highest possible grade each time.[16]

The PM suffered a sprain of the lumbar spine in the accident.[17] He did not receive any medical attention until returning to South Korea, where he was hospitalized from July 14-20, 2013.[18]

1.2.3 The First Officer (FO)

The FO, age 40, was hired by Asiana in 2007. Previously, he served in the Korean Air Force, where he flew the F5 and F16 aircraft.[19] He was initially qualified on the A320 as a first officer, and transitioned to the B777 on March 3, 2012.[20]

At the time of the accident, the FO had 4,557 hours of total flight time, with 1,445 hours as pilot-in-command. His total time as a first officer on the B777 was 715 hours. He had flown seven previous trips to SFO, the most recent of which occurred on May 10, 2013.[21]

The FO also sustained injuries in the accident. He was transported to a San Francisco-area hospital, where he received medical attention for a possible rib fracture.[22]

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[12] *Id.*

[13] *See* Appendix A, Ex. 2, PM's Air Force Flight Record.

[14] Hr'g Ex. 2-A, Operations Group Factual Report at 14.

[15] *See* Hr'g Ex. 2-A, Operations Group Factual Report at 13.

[16] *See* Hr'g Ex. 2-U, PM's B777 Simulator Training Record at *4, *14, *16.

[17] *See* Survival Factors Group Factual Report, Addendum 2, Attach. 1 at 24.

[18] Appendix A, Ex. 1, Flight Crew Medical Records at *4.

[19] Hr'g Ex. 2-A, Operations Group Factual Report at 14.

[20] *Id.*

[21] *Id.* at 15-16.

[22] *See* Survival Factors Group Factual Report, Addendum 2, Attach. 1 at 21; *see also* Hr'g Ex. 2-B, NTSB Interview Summaries at 7, Interview of F.O. Bong Dong Won (FO).

1.2.4 The Cabin Crew

There were 12 experienced flight attendants aboard the accident flight. Nine of the 12 flight attendants had completed a recurrent training course in 2013 prior to the accident flight. The remaining three flight attendants began working at Asiana in June or July 2012 and received their training at that time.[23] Two flight attendants were initially trapped in the airplane and unable to assist passengers in the evacuation when two of the slide rafts deployed inside the airplane on impact. Ten of the 12 flight attendants were injured in the accident, including eight who were deemed to have suffered "serious" injuries.[24] Despite these injuries, the flight attendants performed heroically in the aftermath of the accident.[25]

1.2.5 Passengers

Three of the 291 passengers on board were fatally injured in the accident and the immediate aftermath. One of the passengers who died was struck twice by fire equipment after she was placed on the ground.[26] Of the remaining 288 passengers on board, 174 sustained injuries and 114 suffered no injuries.[27]

1.3 The Accident Flight

Asiana flight 214 departed from Seoul Incheon International Airport at approximately 0:53 PDT on July 6, 2013.[28] The cruise portion of the flight was uneventful. At 9:34 PDT, approximately two hours prior to scheduled landing, the flight crew briefed routine operational issues concerning the approach and landing, including the fact that the glide slope at Runway 28L would not be available.[29] At 10:40 PDT, Air Traffic Control ("ATC") instructed the flight crew to follow the "Golden Gate Six" arrival procedure to SFO.[30] At 10:42 PDT, the PF gave a comprehensive approach briefing, in which he described the crew's plan to perform a visual approach using the localizer for lateral guidance.[31]

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[23] *See* Hr'g Ex. 6-A, Survival Factors Group Factual Report at 4.

[24] Survival Factors Group Factual Report, Addendum 2 at 4.

[25] *See, e.g.,* Hr'g Ex. 6-J, Emergency Response Interview Summaries at 52, Interview of Capt. Anthony Robinson, San Francisco Fire Department ("When asked if he had any comments about his experience he stated that the flight attendants were crucial to the success of the incident. They were the last ones off the airplane and were helping to rescue people trapped by slide/rafts inside the airplane.").

[26] *See* Hr'g Ex. 6-A, Survival Factors Group Factual Report at 57.

[27] Survival Factors Group Factual Report, Addendum 2 at 4.

[28] Hr'g Ex. 2-A, Operations Group Factual Report at 5.

[29] Hr'g Ex. 12-A, CVR Group Factual Report at 12-5.

[30] *Id.*

[31] *Id.* at 12-8. The CVR offers no indication that the flight crew was in any way concerned about performing the visual approach or the lack of an electronic glideslope. *Id.*

As flight 214 neared San Francisco, ATC instructed the flight crew to maintain an altitude of 4,000 feet at a speed of 210 knots.[32] Approximately 17 nautical miles from the airport, the captain informed ATC that he had visual contact with the airport. ATC then cleared the plane for the "Quiet Bridge" visual approach to Runway 28L, and instructed the captain to maintain 180 knots until five nautical miles from the airport.[33] These instructions positioned flight 214 for a "high-energy" approach -- that is, a situation in which an aircraft approaches the runway from a high and fast posture, relative to the altitude and airspeed of a standard approach profile.

At approximately 1,600 feet, recorded data show that the autopilot flight director system ("AFDS") pitch mode changed to flight level change ("FLCH") mode.[34] In post-accident interviews, the PF did not recall pressing the FLCH button at 1,600 feet, nor did the PM or FO recall the PF or anyone else pressing the FLCH button.[35] Upon the engagement of FLCH mode, the throttles advanced to prepare the aircraft to climb towards the missed approach altitude, which had been set at 3,000 feet, and the aircraft's pitch attitude began to increase.[36] Approximately three seconds later, the PF disconnected the autopilot, called out "manual flight,"[37] as required by Asiana procedures, and began to manually fly the airplane.[38] Because the airplane's speed and altitude were still higher than desired at this point, the PF reduced the throttle levers to the idle position. The movement of the throttle levers to the idle position while in FLCH mode resulted in an automatic change of the autothrottle mode from THRUST to HOLD, thereby turning off airspeed protection and disabling the autothrottle wake-up function.[39]

Shortly after the PF disengaged the autopilot, he requested the PM to set the command airspeed to 137 knots, the target speed for the approach.[40] The PF also directed the PM to turn both flight director ("FD") switches off and then turn the right FD switch back on, in accordance with Asiana policy and Boeing guidelines.[41] Recorded data show that the left FD switch was

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[32] *Id.* at 12-25, 12-29.

[33] *Id.* at 12-30, 12-31.

[34] Hr'g Ex. 10-A, FDR Group Factual Report at 10-6.

[35] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 40, Interview of Capt. Lee Kang Kuk (PF) ("Asked why he pushed the flight level change at 1,600 feet, [the PF] said he did not push it. He said, why would he push it because he was high. Asked whether the PM might have pushed it he said 'no way.'"); *see also id.* at 18, Interview of Capt. Lee Jung Min (PM) ("Asked whether they were ever in flight level change mode after [4,000 feet], [the PM] said no.").

[36] Hr'g Ex. 10-A, FDR Group Factual Report at 10-7.

[37] Hr'g Ex. 2-A, Operations Group Factual Report at 6.

[38] Hr'g Ex. 13-A, Aircraft Performance Group Factual Report at 23-24; *see also* Hr'g Ex. 10-A, FDR Group Factual Report at 10-15 (Figure 7).

[39] As discussed in Sections 1.5.2 and 1.6 below, if the autothrottle enters HOLD mode, it will not "wake up" to support stall protection, even in the event of large deviations in airspeed.

[40] Hr'g Ex. 12-A, CVR Group Factual Report at 12-35.

[41] *Id.*

turned off but the right FD switch remained on,[42] but the sampling rate for this parameter -- once every four seconds -- could allow for the switch to be turned off and then quickly turned back on without being recorded on the FDR.[43] In addition, in his interview, the PM stated that he "turned both FDs off and then turned the FD back on on the right side," and that "there was no delay" before he turned the right switch back on.[44]

As the aircraft descended through 1,000 feet, the FO saw the descent rate on the vertical speed indicator was in excess of 1,000 FPM, and made standard callouts of "sink rate" several times in accordance with Asiana procedures.[45] The Cockpit Voice Recorder ("CVR") and recorded data show that the PF acknowledged the FO's callout, and that the sink rate quickly decreased.[46]

The flight crew initially had attempted to contact the tower controller to obtain landing clearance as the aircraft passed through 2,100 feet, but received no reply.[47] Approximately one minute later, just after passing through 1,000 feet, the crew again attempted to establish contact with the tower controller, and eventually the controller responded and issued a clearance to land.[48] At this point, flight 214 was passing through approximately 600 feet.[49]

At 500 feet, the airspeed was 135 knots, slightly below the target speed of 137 knots (but within the acceptable margin of +10/-5 knots), and the precision approach path indicator ("PAPI") lights showed two red and two white.[50] The PF directed the PM to complete the landing checklist, and the PM responded, "checklist complete." The PM also stated that the airplane was "on glide path."[51]

Between 500 feet and 200 feet, an elapsed time of approximately 17 seconds, the airspeed decreased from 135 knots to 118 knots.[52] Around 200 feet, the PM saw four red PAPIs and

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[42] Hr'g Ex. 10-A, FDR Group Factual Report at 10-7.

[43] *Id.* at 10-10 (showing, in Figure 2, that the FD switch parameter is recorded once every four seconds).

[44] Hr'g Ex. 2-B, NTSB Interview Summaries at 19, Interview of Capt. Lee Jung Min (PM)

[45] Hr'g Ex. 12-A, CVR Group Factual Report at 12-36; *see also Asiana Pilot Operations Manual* § 2.13.6.9 [hereinafter, "POM"].

[46] *See* Hr'g Ex. 12-A, CVR Group Factual Report at 12-36 (PF acknowledging FO's sink rate callout); *see also* Hr'g Ex. 10-A, FDR Group Factual Report at 10-7 (noting that sink rate was at its highest at the time the FO made his callout (11:27:05), and that it decreased substantially thereafter).

[47] Hr'g Ex. 3-A, ATC Group Factual Report at 4; Hr'g Ex. 12-A, CVR Group Factual Report at 12-34.

[48] Hr'g Ex. 12-A, CVR Group Factual Report at 12-36.

[49] *Id.*; *see also* Hr'g Ex. 10-A, FDR Group Factual Report at 10-10 (Figure 2).

[50] *See* IIC Opening Presentation at 9.

[51] *See* Hr'g Ex. 12-A, CVR Group Factual Report at 12-36.

[52] *See* Hr'g Ex. 2-A, Operations Group Factual Report at 7; Hr'g Ex. 13-A, Aircraft Performance Group Factual Report at 25.

called out that the plane was too low.[53] Approximately seven seconds later, and just eleven seconds prior to impact, a quadruple chime sounded in the cockpit.[54] The PM responded by pushing the throttles forward and called out "go around."[55] The PF pitched the plane up more than ten degrees in an attempt to go around, but the engines, which had been at idle, were still spooling up and the aircraft continued to lose altitude.[56] The stick shaker activated, and four seconds later the airplane's aft fuselage struck the seawall.[57]

1.4 Asiana Training

1.4.1 Core Flight Crew Training

Asiana employs approximately 1,300 pilots who fly to 71 destinations around the globe on more than 300 flights each day. In order to maintain its reputation for excellence,[58] Asiana has developed a premier flight crew training program that consists of ground school, simulator training, and OE training. Asiana's comprehensive training curriculum covers all aspects of flight operations and meets or exceeds Federal Aviation Administration ("FAA"), Korean, and international standards. All Asiana pilots -- captains and first officers -- are type-rated on the aircraft they fly.

Ground School Training: Asiana conducts the ground school portion of its training in-house in courses taught by experienced pilots trained as flight instructors. Asiana's training materials are based directly on the manuals provided by Boeing -- the Flight Crew Operations Manual ("FCOM") and Flight Crew Training Manual ("FCTM") -- as well as on Asiana's own Flight Operation Manual ("FOM") and Pilot Operation Manual ("POM").[59] These training materials are constantly reviewed and updated based on regulatory developments, information provided by Boeing, data from internal audits, and information gleaned from Asiana's Flight Operational Quality Assurance ("FOQA") program.[60] Additionally, Asiana representatives regularly attend international conferences and carefully monitor guidance from the International Civil Aviation Organization ("ICAO") to make sure all training materials remain consistent with the highest international standards.

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[53] *See* Hr'g Ex. 12-A, CVR Group Factual Report at 12-37.

[54] *Id.*

[55] *Id.*; Hr'g Ex. 10-A, FDR Group Factual Report at 10-7.

[56] *Id.* at 10-10 (Figure 2).

[57] *Id.*

[58] Asiana has garnered numerous awards in recent years for excellence in flight, including the 2012 *Business Traveler* award for "Best Overall Airline in the World," the 2011 *Premier Traveler* award for "Airline of the Year," the 2010 Skytrax award for "Airline of the Year," and the 2009 Air Transport World award for "Airline of the Year."

[59] *See* Appendix A, Ex. 3, Asiana Flight Crew Training Regulations ("FCTR") § 6.1.6.1.

[60] Asiana's FOQA program facilitates the collection and analysis of flight data with the goal of continuously monitoring and improving the safety of its operations. FOQA data and proposed changes to training programs are reviewed during a quarterly Flight Data Analysis meeting of Asiana's Human Factors Committee.

Simulator Training: Since 2002, simulator training at Asiana has been administered by Boeing Korea LLC (formerly Boeing Training Services Korea LLC), a Boeing subsidiary that specializes in flight crew training services. Simulator training allows pilots to acquire substantial aircraft experience and is a key component of the Asiana training program. Asiana contracts with Boeing to administer the training in order to ensure that its program adheres to all manufacturer guidelines and that its pilots have access to the most up-to-date information collected by Boeing from all of its operators.[61] The simulator training administered by Boeing, like all Asiana training, meets or exceeds applicable Korean, FAA and international standards.[62] Asiana develops the simulator profiles and training curriculum, working closely with the Boeing flight instructors, from whom the airline solicits feedback on all training materials and student progress. This close collaboration ensures that the simulator training program can be modified as needed to account for changes in Asiana operations, lessons Boeing has learned from other operators, and information gleaned from FOQA reports.

OE Training: Asiana also conducts the OE portion of the training, in which an experienced and trained instructor pilot accompanies a pilot trainee in the cockpit. Significantly, in order to proceed to the OE phase of training, a pilot must have already completed and passed all ground school and simulator training, including the type rating check ride. During the OE flights, the instructor pilot monitors and advises the trainee as necessary, and the trainee obtains additional operating experience.

1.4.2 B777 Captain Selection and Transition Training

Asiana's selection of B777 captains is conducted in accordance with specified procedures on the basis of pilot skill, experience, and qualifications. Asiana's aircraft are categorized into small type and large type, the latter of which includes the B777. To be eligible for transitioning to the B777, captains must have had more than five years of experience as captains of small-type aircraft. Starting from this pool of eligible pilots, the selection process is then based on a careful individual evaluation of each pilot's record, skills, and seniority, as determined by senior Asiana flight officers.

Once selected to become a B777 captain, pilots-in-transition are then required to complete a rigorous training program. In the past, this training program included 160-168 hours of ground school, 22 hours of simulator training, four days of pre-OE ground school, and 20 legs of OE training.[63] Although these requirements already exceeded regulatory standards, Asiana has further increased the required training in each of these areas since the accident, as detailed in Appendix C.[64] This training covers a complete range of subjects, including aircraft systems and automation, non-precision approach, special airports, and threat and error management.

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[61] Boeing Korea, in turn, contracts with Cambridge Communications Limited ("CCL") to fill its flight instructor positions. Hr'g Tr. at 95:7, Statement of Capt. Darren Gulbransen, Boeing Manager of Simulator Flight Training.

[62] *See id.* at 96:7.

[63] *See* Hr'g Ex. 2-V, Selected Actions Taken in Response to SFO Accident at *3.

[64] *See also id.*

Asiana's Flight Crew Training Regulations provide greater detail about the transition training curriculum.[65]

Asiana's B777 Chief Pilot maintains and oversees the progress made by trainee captains and ensures that the training is progressing normally. If a pilot fails to satisfy training standards, the pilot's training records are referred to Asiana's Eligibility Committee for review and further action as necessary..

1.4.3 Instructor Pilot Selection & Training

Only Asiana pilots with extensive experience and qualifications are considered to serve as B777 flight instructors. At a minimum, Asiana flight instructors must have 500 or more flight hours as pilots in command on a B777, possess strong ground school and flight training records, demonstrate competency and proficiency in aircraft operation, and must not have failed a check ride or violated any aviation regulation within the preceding year. From this pool of eligible candidates, the Instructor Selection Committee, headed by a Senior Executive Vice President of the airline, selects instructor pilots based on pilot skills, training records, and an in-person evaluation interview.[66]

Asiana's instructor pilots are required to complete intensive training prior to their first instructor flight. Prior to the accident, this training program included 18 hours of ground school, 14 hours of simulator training, OE training, and a final evaluation check ride.[67] Again, although this program already satisfied applicable requirements, Asiana has further enhanced each of these training requirements since the accident.[68] The flight instructor training covers a complete range of subjects, which are illustrated in detail in Section 6 of Asiana's B777 Flight Instructor Training Guide.[69] Asiana instructor pilots also receive extensive training on the roles and responsibilities of the PM and PF during all phases of their initial flight instructor training, and candidates to become flight instructors must successfully complete a two-leg evaluation check ride -- one leg as PF, and one leg as PM -- prior to completion of training. No instructor pilot is cleared to supervise a training flight until he or she has fully and satisfactorily completed all training requirements.

1.4.4 Crew Resource Management

Asiana began providing Crew Resource Management ("CRM") training to pilots in 1994 -- eight years before the Korean Office of Civil Aviation first required such a course -- and the airline has continuously monitored and improved its CRM program over the past 20 years.[70] CRM training focuses on communication, teamwork, and problem-solving in the cockpit.

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[65] *See* Appendix A, Ex. 3, Asiana FCTR.

[66] *See* Operations Group Factual Report, Addendum 1, Attach. 9 § 3.

[67] *See* Appendix C, Asiana Post-Accident Training Enhancements.

[68] *Id.*

[69] *See* Operations Group Factual Report, Addendum 1, Attach. 9 at 3-6.

[70] Hr'g Ex. 14-A, Human Performance Group Factual Report at 8.

Asiana's core initial CRM training is a three-day intensive course developed in-house based on materials from ICAO, the International Air Transport Association, and the University of Southern California. The program covers all 20 subject matters enumerated in Korean Flight Safety Regulations (Appendix Section 8.3.4.4 and 8.3.4.13).[71]

While some international standards require an initial CRM course only, Asiana has developed a full curriculum of CRM training courses. A one-day refresher CRM course was implemented in 2010 in response to a recommendation based on line oriented safety audits, and all pilots must attend the refresher course six months after completion of initial CRM training.[72] Pilots also are required to attend a one-day joint CRM class, which includes flight attendants, mechanics, system operators, controllers, and dispatchers. Additionally, pilots in the process of transitioning to captain or flight instructor status or upgrading to a larger aircraft also are required to undergo another one-day CRM training course.[73] Finally, Asiana has also developed an innovative family CRM course for family members of Asiana pilots. The course focuses on the source and effect of stress on cockpit performance and strategies for stress management at home.[74]

All members of the accident crew were up-to-date with their CRM training. The PF had completed recurrent training on April 30, 2013.[75] The PM completed recurrent CRM training on April 30, 2013, and had completed joint CRM training on July 4, 2013, two days before the accident flight.[76] The FO had completed recurrent CRM training on April 30, 2013.[77]

1.4.5 Subject Area Training

Visual Approach Training: Visual approaches are covered in detail during initial ground school and simulator training, as well as during recurrent training. Six of Asiana's B777 transition simulator profiles incorporate a visual approach component, including SIM Profile #6, which specifically includes a high-energy visual approach to runway 28L at SFO.[78] A recurrent training module called "Approach and Landing Aids Out" is provided biannually, and Asiana's B777 recurrent simulator training has covered visual approaches to SFO each of the past four years.[79] Asiana also trains its pilots on the use of the VNAV path pointer for vertical guidance when a glide slope is not otherwise available, although whether to use this function during a

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[71] *Id.* at 9.

[72] *Id.*

[73] *Id.*

[74] *Id.* at 10.

[75] *Id.*

[76] *Id.*

[77] *Id.*

[78] *See* Operations Group Factual Report, Addendum 1, Attach. 10, "B777 Transition Simulator Training Profiles."

[79] *See* Operations Group Factual Report, Addendum 1, Attach. 11, "Asiana Recurrent Simulator Training: 2010 to 2013."

visual approach is a matter of pilot discretion depending on flight conditions and the approach profile.[80]

In addition to formal visual approach training, Asiana pilots also possess significant practical experience making visual approaches. Many airports serviced by Asiana in Japan and Korea commonly require final approaches without glideslope guidance,[81] and Asiana pilots must fly these shorter routes first before they are eligible to upgrade to the B777. Thus, all Asiana B777 pilots have extensive practical line experience flying visual approaches on shorter regional flights before they even begin flying the B777.

The pilots' comfort performing visual approaches is clear from the NTSB's interviews of Asiana B777 line pilots. For instance, one pilot interviewed stated that he felt confident making a visual approach with no glideslope, and that he did not think there was anything special about making a visual approach.[82] Another B777 pilot told the NTSB that he was very confident in his ability to fly a visual approach in the B777 without glideslope or glide path information, and that he did not notice any nervousness among pilots with less experience when performing visual approaches.[83] And the B777 Chief Captain echoed these sentiments both in his hearing testimony[84] and in his interview with investigators, stating that "Asiana pilots were expected to be able to fly a visual approach with no flight path cues, such as a glideslope or vertical path indicator such as a PAPI."[85]

Boeing instructor pilots have also explained Asiana pilots' readiness to fly visual approaches. At the public hearing, Captain Rod McNaughton, Boeing Korea's Manager of Flight Training, stated several times that he was comfortable with the level of training provided to Asiana pilots on visual approaches and manual flying skills. Captain McNaughton explained that Asiana's B777 pilots have "considerable background" in flying visual approaches, that Asiana pilots "have the opportunity to learn these manual flying skills on visual approaches," and that Asiana provides its pilots with "the same [stall recovery training] as laid down in the Boeing flight crew training manual."[86] Similarly, a simulator instructor hired by Boeing to train

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[80] Hr'g Tr. at 101:12-13, Statement of Capt. Rod McNaughton, CCL Manager of Flight Training – Boeing Korea (stating that use of the vertical path pointer was "something that is emphasized for sure" in Asiana training).

[81] *See, e.g.*, Gimhae International Airport (PUS), Kumamoto Airport (KMJ), Fukuoka Airport (FUK), Shizuoka Airport (FSZ), Toyama Airport (TOY), and Miyazaki Airport (KMI).

[82] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 86, Interview of Capt. Park Ho Yeoul, Asiana B777 Captain.

[83] *Id.* at 69, Interview of Capt. Kim Jae Jung, Asiana B777 Captain.

[84] Hr'g Tr. at 110:16, Statement of Capt. Lee Sung Kil, Asiana B777 Chief Pilot (confirming that he "[did] not have any concern" about the ability of Asiana pilots to land at SFO without a glide slope).

[85] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 46, Interview of Capt. Lee Sung Kil, Asiana B777 Chief Pilot.

[86] *See* Hr'g Tr. at 101:23-102:17, 104:17-105:9, 103:17-104:8, Statement of Capt. Rod McNaughton, CCL Manager of Flight Training – Boeing Korea.

Asiana pilots reported that the pilots performed the visual approach profile “quite well” during simulator training.[87]

Automation Training: Asiana pilots receive extensive training on aircraft automation systems in ground school, simulator training, and OE training.[88] Significantly, during ground school in April 2013, the PF and other trainee captains were taught that when descending in FLCH mode with the throttles reduced to idle, the autothrottle would go into HOLD mode and would not wake up, even when airspeed decays well below the command airspeed. Specifically, Captain Kim Je Youl, an Asiana instructor pilot with more than 6,000 hours of flight time in the B777, explained to the PF and other trainee captains that on three occasions during high-energy visual approaches in FLCH mode -- including twice at SFO -- the B777’s autothrottle switched to HOLD and did not provide airspeed protection. Captain Kim explained that he made a point to tell trainee pilots about this “anomaly” because he remembered being “surprised that the autothrottle did not maintain the selected target airspeed.”[89] He also recalled that the PF attended the lecture that day and asked follow-up questions about the topic.[90]

Notes taken by Captain Jung Tai Soo, another student in the ground school class, show that Captain Kim illustrated this feature of the automation by using the example of a high-energy visual approach to SFO.[91] Captain Jung’s notes also indicate that several days later, this same lesson was imparted by another Asiana instructor pilot, Captain Kwon Young Sik. Like Captain Kim, Captain Kwon warned the trainee captains that FLCH should not be used after the final approach fix, particularly on a high and fast descent while on visual approach to runway 28L at SFO because, in certain circumstances, the autothrottle would switch to HOLD mode and would not support speed protection.[92]

Monitoring Training: Monitoring and crosscheck training is provided in every Asiana simulator training, and a module dedicated to monitoring also is incorporated into Asiana’s core three-day CRM course.[93] In this respect, Asiana exceeds current FAA training guidelines, which do not require all pilot training programs to contain segments dedicated to developing

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[87] *See* Hr’g Ex. 2-B, NTSB Interview Summaries at 108, Interview of Mr. David Geekie, Chief Flight Instructor, Cambridge Communications Limited.

[88] For example, ground school courses offered as part of B777 captain transition training cover topics such as FCOM and FCTM guidance, autoflight, flight control, flight management, POM normal procedures, and SIM cockpit time. *See* Appendix A, Ex. 3, Asiana FCTR § 6.1.6.1.

[89] *See* Hr’g Ex. 2-D, Statement of Capt. Kim Je Youl.

[90] *Id.*

[91] Hr’g Ex. 2-D, Statement of Capt. Jung Tai Soo, and attachments thereto.

[92] *Id.*

[93] Appendix A, Ex. 4, Asiana Monitoring Training Module; *see also* Hr’g Ex. 2-B, NTSB Interview Summaries at 92, Interview of Capt. Yim Moon Sik, Asiana Lead CRM Instructor (confirming that Asiana’s CRM training includes a “special emphasis on monitoring skills”).

monitoring skills.[94] Additionally, Asiana also offers dedicated training on monitoring during its CRM session as part of instructor training. Asiana's Safety Management System program, which is based on ICAO guidance, also includes a component addressing feedback and monitoring.[95] Finally, monitoring skills are also reinforced by simulator training and OE training flights. Trainee captains and instructor pilots are evaluated on monitoring skills as an independent check item on each training flight,[96] and Asiana flight instructors also emphasize the importance of monitoring during these phases of training. For instance, a flight instructor who accompanied the PF on several legs of his OE training recalled that he "emphasized crosschecking and monitoring" to the PF during a post-flight debriefing and recommended that the PF "continue monitoring flight instruments and callout changes."[97]

Manual Flying Skills: Asiana's automation policy states that for the interests of safety, work load minimization, and enhanced flight capability, cockpit crews shall use autopilot and autothrottle whenever appropriate, particularly in the terminal area or in non-normal circumstances.[98] In this respect, Asiana's policy is consistent with Boeing's guidelines on the use of automation, which provide that flight crews should assume "the full use of all automated features."[99] If pilots find that aircraft automation is behaving in an unexpected or undesirable way, however, Asiana trains its pilots to disconnect the automation and fly the plane manually.[100] This, too, matches Boeing's guidance.[101]

Asiana policy calls for the disengagement of autopilot by 500 feet above ground level ("AGL") for a manual landing, meaning that Asiana pilots rely primarily on manual flying skills

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94 *See* NTSB Recommendation No. A-10-010 (Feb. 23, 2010), *available at* <http://www.ntsb.gov/doclib/recletters/2010/A-10-010-034.pdf> (recommending that the FAA require a dedicated monitoring training module in all flight crew training).

95 *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 53, Interview of Capt. Park Il Jae, Asiana VP of Safety and Security.

96 *See* Hr'g Ex. 2-T, PF's B777 Simulator Training Record; Hr'g Ex. 2-S, PF's B777 OE Training Record; Hr'g Ex. 2-U, PM's B777 Simulator Training Record.

97 *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 84, 85, Interview of Capt. Park Ho Yeoul, Asiana B777 Captain.

98 *See* POM § 2.1.6.2.

99 *See* FCOM § NP.11.1 ("Normal procedures are used by a trained flight crew and assume . . . the full use of all automated features."); *see also* FCTM § 5.27 ("Automatic flight is the preferred method of flying non-ILS approaches. Automatic flight minimizes flight crew workload and facilitates monitoring the procedure and flight path. During non-ILS approaches, autopilot use allows better course and vertical path tracking accuracy, reduces the probability of inadvertent deviations below path, and is therefore recommended until suitable visual reference is established on final approach.").

100 *See* Appendix A, Ex. 5, Asiana Automation Training Presentation at *7 ("When A/P is not maintaining intended flight path, A/P and A/T → disconnect.").

101 *See* Hr'g Tr. at 180:23-181:5, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering ("If [pilots] get behind the airplane or if there's an automation surprise, we expect them to back off on the level of automation as required and revert to more basic skills, either by flying off just the basic modes of the autopilot, for example, or going purely to manual flight. And we expect them ultimately, if the airplane is not doing what they expect it to do, that they can disconnect the automation altogether and fly manually.").

during landings.[102] Indeed, in 2012, approximately 83% of B777 landings were conducted manually.[103] First officers also receive frequent opportunities to apply their manual flying skills, as approximately 36% of Asiana B777 landings in 2012 were performed by a first officer.[104]

Stabilized Approach and Go-Around Training: Asiana's stabilized approach criteria, described in detail in Section 2.13.6.5 of the POM, and stabilized approach standards are covered during all phases of pilot training. In visual meteorological conditions, the following criteria must be satisfied at 500 feet AGL:

1. aircraft is on course (track);
2. aircraft is on glide path (angle);
3. appropriate speed (between +10 knots and -5 knots);
4. appropriate landing configuration;
5. appropriate sink rate (less than 1,000 feet per minute);
6. appropriate power setting for engine; and
7. all checklists complete.

If an approach becomes unstable below 500 feet AGL in a visual approach, Asiana trains its pilots to execute a go-around immediately. Although the captain has primary responsibility for deciding whether to go around, Asiana policy is that *any pilot* can call for a go-around, a point which is emphasized in Asiana's CRM training. Numerous Asiana pilots confirmed this policy during interviews with NTSB investigators. For example, Asiana's B777 Chief Pilot stated that "anyone in the cockpit could call for a go around," and Asiana's Training Manager confirmed that "Asiana trained pilots to understand that anyone could call for a go around."[105] Asiana first officers echoed the understanding that any pilot can initiate a go-around,[106] and the PM also confirmed that this was the case.[107] In his interview, the PF initially stated that only the pilot-in-command could call for a go-around, but he later clarified that "Asiana had a policy

[102] *See* POM § 2.14.1.4

[103] *See* Hr'g Ex. 2-K, Asiana Landing Statistical Data. This figure refers to landings that are not full auto-landings, including precision approaches using ILS, visual approaches, and circling approaches.

[104] *Id.*

[105] Hr'g Ex. 2-B, NTSB Interview Summaries at 45, Interview of Capt. Lee Sung Kil, Asiana B777 Chief Pilot; *id.* at 51, Interview of Capt. Yoo Byung Geoun, Asiana Training Manager; *see also id.* at 44, Interview of Capt. Lee Jong Joo, Asiana B777 Captain (stating that "anyone can initiate a go around during final approach, not only the captain or only the pilot flying"); *id.* at 78, Interview of Capt. Oh Cheol Woo, Asiana B777 Captain (stating that "in a dangerous situation, if safety was compromised, that anybody could make a go around," and that "this situation was discussed in CRM training").

[106] *See, e.g.*, *id.* at 59, Interview of F.O. Kim Young Chae, Asiana B777 First Officer (stating that in a potentially dangerous approach, he would "say loudly 'Go around!'" and "take control [of the aircraft] if the captain did not go around"); *id.* at 65, Interview of F.O. Han Ka Ram, Asiana B777 First Officer (confirming that "either pilot could decide that a go around was necessary").

[107] *See id.* at 17, Interview of Capt. Lee Jung Min (PM) ("Asked whether an FO could call for go around, [the PM] said yes. Asked whether the PF on the accident flight could have called for a go around, [the PM] said yes, he was allowed to do so.").

encouraging junior pilots to speak up if they felt uncomfortable about something," and that "if he felt there was something unsafe going on during the flight he could bring that to the PM's attention."[108]

Asiana encourages pilots to initiate go-arounds, without penalty, any time there is a potential issue involving safety. For instance, one first officer reported that Asiana "strongly recommended a go around any time safety was not confirmed," and that every go-around he had been involved in had been "free of any repercussion" from the airline.[109]

Special Training for SFO: SFO has been designated a "special airport" by the Korean Ministry of Land, Infrastructure and Transportation ("MOLIT") because of the unique circumstances and challenges that it presents to pilots.[110] The approach to SFO is often high and fast due to required air traffic and noise abatement practices and procedures of the Northern California TRACON and other air traffic control facilities, and it therefore merits specialized training. Additionally, the close spacing of the two parallel runways (28R and 28L) requires additional monitoring in visual conditions.[111] As mentioned, the simulator portion of B777 transition training includes training specific to SFO in SIM Profile #6, and Asiana also conducts further training for SFO in the second half of each year. Visual approaches -- including approaches to runway 28L -- are specifically addressed.[112]

1.5 Aircraft Information

1.5.1 Autopilot Flight Director System Pitch Modes

The B777 AFDS has ten pitch modes.[113] One of these pitch modes, the flight level change ("FLCH") speed mode, warrants particular attention here. In general, FLCH mode is used for varying an aircraft's altitude while in cruise flight. Additionally, Boeing's FCTM states that "use of the autopilot with FLCH mode is the recommended technique for rapid descents."[114] Boeing's FCTM also states that "[a]utothrottles should be left engaged" when using FLCH mode.[115] FLCH mode can be engaged by pressing the "FLCH" pushbutton on the control panel, at which point "FLCH" displays in green letters on the primary flight display.

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[108] *Id.* at 25, 31, Interview of Capt. Lee Kang Kuk (PF).

[109] *See id.* at 63, Interview of F.O. Kim Young Chae, Asiana B777 First Officer.

[110] Hr'g Ex. 2-A, Operations Group Factual Report at 30.

[111] *See* Hr'g Tr. at 181:17-19, Statement of Mr. Tryg McCoy, Chief Operating Officer of SFO (indicating that 750 feet separate parallel runways 28R and 28L).

[112] *See* Operations Addendum 1, Attach. 11, "B777 Recurrent Training Profiles 2010–2013."

[113] *See* FCOM § 4.10.17.

[114] FCTM § 7.7 (emphasis added).

[115] *Id.*

1.5.2 Autothrottle Functioning

In almost all situations, the B777's autothrottle system supports stall protection and ensures that the aircraft maintains a safe airspeed. However, if a plane is in FLCH mode, the autothrottle will enter HOLD mode if: (1) the throttles are at the aft stop (*i.e.*, engine is in idle); or (2) the throttles are manually overridden. In HOLD mode, the autothrottle is engaged (on), but it does not provide any input to the throttle levers or engines. The servos are disengaged from the throttle levers.[116] Therefore, while the autothrottle is technically on, it is providing no service to the flight crew. As a result, if the autothrottle enters HOLD mode, the autothrottle will not support stall protection, even in the event of large deviations in airspeed, by "waking up."

Boeing makes clear that the autothrottle is an essential tool, stating that "[a]utothrottle use is recommended during all phases of flight," including "[w]hen in manual flight."[117] Boeing's manuals repeatedly state that the autothrottle system provides comprehensive airspeed control and stall protection:

- *FCOM § 4.20.8:* "The autothrottle system provides thrust control from takeoff through landing."

- *FCOM § 4.20.9:* "The autothrottle can support stall protection when armed and not activated. If speed decreases to near stick shaker activation, the autothrottle automatically activates in the appropriate mode (SPD or THR REF) and advances thrust to maintain minimum maneuvering speed (approximately the top of the amber band) or the speed set in the mode control speed window, whichever is greater."

- *FCOM § 4.20.13:* "The autothrottle adjusts thrust quickly when airspeed decreases below command speed."

- *FCTM § 7.11:* "When the speed decreases approximately half way through the amber band, the AIRSPEED LOW caution message appears. The autothrottle wakes up, automatically engages in the SPD mode, and returns the airplane to the minimum maneuver speed."

In contrast to the repeated references to the comprehensive airspeed protection provided by the autothrottle system, the Boeing 777 FCOM contains only a single, one-sentence note which can be read to suggest that autothrottle will not support speed protection when in FLCH mode. The note reads: "When the pitch mode is FLCH or TOGA, or the airplane is below 400 feet above the airport on takeoff, or below 100 feet radio altitude on approach, the autothrottle will not automatically activate."[118]

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[116] *See* FCOM 4.20.6.

[117] FCTM § 1.34.

[118] *See* FCOM § 4.20.9. Boeing moved this statement from Chapter 9 of the FCOM to Chapter 4 of the FCOM in 2012. *See* Hr'g Ex. 14-A, Human Performance Group Factual Report at 16 n.20. On the same page, the FCOM also states: "During a descent in VNAV SPD, the autothrottle may activate in HOLD mode and will not support stall

As explained further in Section 1.6 below, the FAA directed Boeing to include, in the B787 Airplane Flight Manual ("AFM"), a longer and more detailed note describing the autothrottle's lack of airspeed protection when in HOLD mode during descent in FLCH.[119] The note reads: "During a descent in FLCH mode or VNAV SPD mode, the AT may activate in HOLD mode. When in HOLD mode, the AT will not wake up even during large deviations from target speed and does not support stall protection."[120] The FAA required Boeing to add this note after the lead FAA test pilot for the B787, Captain Eugene Arnold, observed a safety issue with respect to the aircraft's autothrottle system when descending in FLCH mode. Captain Arnold also recommended that Boeing insert this note in its B777 FCOM since the B777's autothrottle exhibits the same inconsistency. Boeing declined to do so.[121]

1.5.3 Airspeed Alert

The B777 has three levels of alerts: warnings, cautions, and advisories.[122] The FCOM describes these levels of alerts as follows:

- <u>Warnings</u>: "highest priority" alerts; displayed in red lights; cannot be manually canceled; require "immediate crew awareness and corrective action."[123]

- <u>Cautions</u>: "next highest priority" alerts; displayed in amber lights; may be manually canceled; require "immediate crew awareness."[124]

- <u>Advisories</u>: "lowest priority" alerts; displayed in green lights; may be manually canceled; require "routine crew awareness."[125]

The low airspeed alert, which sounded 11 seconds before impact on the accident flight, is a "caution," not a "warning."[126] As such, it calls for immediate crew "awareness," not immediate crew "action."[127] The low airspeed caution is signaled by a quadruple chime. This quadruple chime is referred to as the "master caution alert" because the sound is identical to, and indistinguishable from, the caution alert associated with more than 70 other potential issues in

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protection." *Id.* Significantly, this note does not address autothrottle behavior when in FLCH mode or describe the circumstances in which the autothrottle "may" activate in HOLD mode.

[119] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 120, Interview of Capt. Eugene Arnold, FAA Test Pilot.

[120] *Id.*

[121] *See id.* at 120-21.

[122] *See* FCOM § 15.10.2.

[123] *See id.* Boeing designates some warnings as "time critical warnings." *Id.* § 15.20.1.

[124] *See id.*at § 15.10.2.

[125] *See id.*

[126] *See* Hr'g Ex. 14-C, FCOM § 15.20.12.

[127] *See* FCOM § 15.20.1.

the airplane.[128] Boeing has indicated that the low airspeed alert was originally designed for an aircraft at cruise altitude, which is the reason it classifies the low airspeed alert as only a "caution" and not a "warning."[129]

1.6 Federal Aviation Administration and European Aviation Safety Agency Concerns with Boeing 787 Autothrottle System

As part of the Boeing 787 certification process, both the FAA and the European Aviation Safety Agency ("EASA") conducted flight tests on the B787 aircraft, which shares the same autothrottle operation and design as the B777.[130] Both regulators identified a significant safety concern that is directly relevant to Asiana flight 214.[131]

On August 30, 2010, Captain Eugene Arnold, the lead FAA test pilot for the B787, encountered a "surprise" in the functioning of the B787 autothrottle.[132] He explained that while in descent on a test flight, he observed the plane's airspeed begin to "decrease considerably, well below maneuvering speed," such that he had to push the throttle levers forward manually to regain maneuvering airspeed.[133] Captain Arnold subsequently drafted FAA Response Item Report Number 12, in which he wrote that "[w]hen in a descent such as FLCH with the autothrottle in THR HOLD mode . . . the autothrottle will stay in THR HOLD mode and will not wake up as it does when you capture the original altitude. The speed will decrease well past maneuvering speed." Captain Arnold stated that this issue had "caught him by surprise," and he "thought that a line crew would have [the] same uncertainty about how the system might function."[134] Specifically, he stated that "the safety issue was that the AT system did not function the way he had expected or assumed it would operate."[135] In light of this safety issue, Captain Arnold's report concludes with the following recommendation for enhancements to the B777's Flight Management Computer System ("FMCS") software: "The FAA strongly encourages Boeing to implement an FMCS enhance in some future [FMCS] software release that would allow autothrottle wake up during large excursions from target speed."[136]

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[128] *See* Hr'g Tr. at 69:21-24; 85:5-16, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[129] *See* Hr'g Tr. at 50:16-23, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[130] *See* Appendix A, Ex. 6, FAA Response Item Report No. 12 at 2 (explaining that the B787's autothrottle operation "is unchanged from the 747, 767, and 777 baselines"); *see also* Hr'g Ex. 2-B, NTSB Interview Summaries at 122, Interview of Capt. Eugene Arnold, FAA Test Pilot (explaining that the autothrottle functioning of the B787 and B777 are "very similar").

[131] *See generally* Hr'g Ex. 2-B, NTSB Interview Summaries at 117-26, Interview of Capt. Eugene Arnold, FAA Test Pilot; Hr'g Ex. 14-I, EASA Debrief Note.

[132] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 122.

[133] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 119, Interview of Capt. Eugene Arnold, FAA Test Pilot.

[134] *Id.*

[135] *Id.* at 122.

[136] Appendix A, Ex. 6, FAA Response Item Report No. 12 at 3.

EASA identified the same autothrottle safety issue during its own testing of the B787 in May 2011. As a result, EASA issued Major Recommendation for Improvement #3, which stated as follows:

> Unfortunately there are on the B787 (as well as some other previous Boeing models) at least two automation modes (FLCH in descent and VNAV speed in descent, with ATHR on HOLD) for which the autothrottle wakeup function is not operative and therefore does not protect the aircraft. Although the certification team accepts that this autothrottle wakeup feature is not required per certification requirements, these two exceptions look from a pilot's perspective as an inconsistency in the automation behavior of the airplane. Inconsistency in automation behavior has been in the past a strong contributor to aviation accidents. The manufacturer would enhance the safety of the product by avoiding exceptions in the autothrottle wakeup mode condition.[137]

Industry sources have also made note of this inconsistency and dubbed it the "FLCH trap."[138] According to the aviation press, the FLCH trap is "a known problem in the industry."[139]

When the autothrottle system is disconnected, the B777 provides both visual and aural caution alerts. There are no similar caution alerts for entering HOLD mode, even though the functional effect of HOLD mode is to disconnect the autothrottle from the aircraft; rather, the only indication is the appearance of green letters reading "HOLD" on the primary flight display. If disconnected, the autothrottle system remains armed and will automatically re-engage if the aircraft drops below maneuvering speed. In contrast, when the autothrottle system engages in HOLD mode, it will not wake up even in the event of large deviations in airspeed.

1.7 Seattle Simulator Testing

The NTSB conducted a Simulator Observational Study of the accident flight from January 21-23, 2014, in Seattle, Washington, using two test crews of B777 pilots from Boeing and the FAA. Each flight crew performed ten test flights, half of which simulated a "standard"

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[137] *See* Hr'g Ex. 14-I, EASA Debrief Note at 6.

[138] *See, e.g.*, Appendix A, Ex. 7, John Croft, *Aviation Week*, "Murky Mode: Boeing Defends Design Philosophy for 777 Autothrust Mode," Dec. 16, 2013; John Croft & Guy Norris, *Aviation Week*, "Were Asiana Pilots Caught in the FLCH 'Trap'?," July 22, 2013, *available at* <http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_07_22_2013_p25-597816.xml>; James Fallows, *The Atlantic*, "Professional Pilots on the San Francisco Crash: On the 'FLCH trap' and Other Possibilities," July 7, 2013, *available at* <http://www.theatlantic.com/national/archive/2013/07/professional-pilots-on-the-san-francisco-crash/277563/>; Robert Goyer, *Flying Magazine*, "Asiana 214 Crash: Lessons Learned," July 9, 2013, *available at* <http://www.flyingmag.com/blogs/going-direct/asiana-214-crash-lessons-learned>; Stephen Stock et al., "An Automation Trap for Pilots?" *available at* <http://www.nbcbayarea.com/investigations/An-Automation-Trap-for-Pilots-221875391.html>.

[139] Appendix A, Ex. 7, John Croft, *Aviation Week*, "Murky Mode: Boeing Defends Design Philosophy for 777 Autothrust Mode," Dec. 16, 2013.

approach profile, and half of which replicated the "accident profile," including the altitude and speed restrictions issued to the accident flight crew by ATC. Both crews had difficulty achieving a stabilized approach by 500 feet under conditions matching the accident profile (a high and fast start position of 2,100 feet MSL at an airspeed of 175 knots).[140] In fact, the aircraft was considered unstable due to excessive sink rates on four of the ten test flights conducted under conditions matching the accident profile. Additionally, on one test flight, the aircraft was unstable because the throttle levers were still at the idle position at 500 feet. And on two other test flights, the aircraft was deemed unstable because it was too high or too fast, respectively. Moreover, even where the test crews were able to attain a stabilized approach profile by 500 feet, they were forced to exceed Asiana's maximum recommended descent rates in order to do so.[141] Indeed, both test crews exceeded Asiana's descent rate guidance below 1,000 feet on all ten test runs that began from a high start position.[142]

In addition to the common challenge of attaining a stabilized approach profile from a high and fast start, the simulator testing also highlighted the difficulty of using VNAV to descend from a high and fast start. During one simulation under these conditions, the FAA test pilot experienced a significant airspeed deviation of seven knots below the approach speed.[143] The test pilot later reported that he would not recommend use of VNAV to descend from a high and fast start, stating: "[M]y conclusion is, if you're above the path and fast (i.e. 'high and fast'), don't try and fix the problem with VNAV . . . many reasons for that conclusion, including: induces potential for automation confusion and (as evidenced in this particular condition) it doesn't do it particularly well."[144] Significantly, the test pilot also acknowledged being confused by the B777's automation on the test flight that experienced a large airspeed deviation. He explained that he was "[c]onfused about why speed [was] low," and that he "thought [autothrottle] was not working right."[145]

Additional simulator testing was also performed to evaluate aircraft performance in an event scenario match and four hypothetical go-around scenarios. This simulation study indicated that the accident aircraft (a B777-200ER with Pratt & Whitney 4090 engines) had "adequate performance capability to accomplish a go around initiated no later than 11 to 12 seconds prior to ground impact."[146] The testing ultimately concluded that the latest time during the accident flight at which a "normal go-around [was] still possible" was 12 seconds prior to ground

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[140] *See* Human Performance Group Factual Report, Addendum 2 at 8.

[141] *Id.*; *see also* Operations Group Factual Report, Addendum 1, Attach. 3 (Asiana FOM Maximum Descent Rates).

[142] *Id.* at 7. The test crews also agreed that to maintain a within-guidelines descent rate from a high-energy approach "required a high degree of pilot attention to sink rate, [which] prevented them from making aggressive early corrections to the flight path, and delayed stabilization." *Id.* at 8.

[143] *Id.* at 9 n.6.

[144] *Id.*

[145] *Id.*

[146] Aircraft Performance Group Study Addendum at 2.

impact.[147] On the accident flight, the quadruple chime low airspeed caution sounded 11 seconds prior to ground impact.

2. ANALYSIS

2.1 Overview

The crash of flight 214 was the result of a unique and complex chain of interrelated events. The record makes clear that the flight crew members were thoroughly trained and well-equipped to complete the approach to SFO without incident. Nevertheless, the accident flight crew did not ensure a minimum safe airspeed. The investigation also reveals, however, a number of other contributing causes of the accident, including inconsistencies in the B777's automation logic that led to the unexpected disabling of airspeed protection, a low airspeed alerting system that activated too late to permit recovery of the flight, and air traffic control demands that led to excessive pilot workload during final approach.[148]

2.2 Flight Crew Preparedness & Performance

As detailed in Section 1.4, Asiana pilots are trained under a comprehensive program that meets or exceeds FAA, Korean, and international standards. As a result, every Asiana pilot is fully prepared to handle any reasonable scenario encountered in the air. The pilots of flight 214 had successfully completed this rigorous program, and were armed with the training they needed to perform the approach to SFO successfully. Despite the comprehensive training provided to the crew, the accident pilots failed to avert an accident that may have been prevented had Asiana's policies been followed.

2.2.1 Pilot Use of Automation

During the approach, the activation of FLCH pitch mode at approximately 1,600 feet interrupted the vertical profile by causing the throttles to advance in order to permit the airplane to begin climbing toward the missed approach altitude of 3,000 feet.[149] Within approximately three seconds, the PF disconnected the autopilot, called out "manual flight," and pulled the

[147] *Id.* at 14.

[148] The pilots were properly certificated and qualified in accordance with applicable Korean, ICAO, and FAA regulations. The airplane was properly certified, equipped, and maintained in accordance with all applicable regulations. The recovered components of the aircraft showed no evidence of any pre-impact structural, engine, or system failures. No evidence indicated any preexisting medical conditions that might have adversely affected the pilots' performance during the accident flight. Weather was not a factor at the time of the accident.

[149] Investigation was unable to determine the exact cause of the change to FLCH mode at 1,600 feet. In post-accident interviews, the PF did not recall pressing the FLCH button at 1,600 feet, nor did the PM or FO recall the PF or anyone else pressing the FLCH button. *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 18-20, Interview of Capt. Lee Jung Min (PM); *see id.* at 40, Interview of Capt. Lee Kang Kuk (PF) ("Asked why he pushed the flight level change at 1,600 feet, [the PF] said he did not push it. He said, why would he push it because he was high. Asked whether the PM might have pushed it he said 'no way.'"). Indeed, engagement of FLCH at this point of the descent would have been counterproductive, as the flight crew was focused on descending and reducing airspeed.

throttles back to idle to maintain the descent.[150] This action reflected Asiana's automation policy taught to all pilots: that pilots should choose the appropriate level of automation for each situation, and that they should disconnect automation when it does not maintain the intended flight path.[151] Moreover, by transitioning into manual flight when the automation began to command a climb, the PF also acted in accord with Boeing's guidance on using automation, as that guidance was explained by Mr. Robert Myers, Boeing's Chief Engineer of Flight Deck Engineering, at the public hearing:

> [I]f there's an automation surprise, we expect [pilots] to back off on the level of automation as required and revert to more basic skills, either by flying off just the basic modes of the autopilot, for example, or going purely to manual flight. And we expect them ultimately, if the airplane is not doing what they expect it to do, that they can disconnect the automation altogether and fly manually.[152]

However, when the PF initiated manual flight by disengaging the autopilot and the throttles moved to idle, the autothrottle system automatically entered HOLD mode, thereby disabling airspeed protection or autothrottle wake-up capability. This automation change was the result of an anomaly in the B777's automation logic, commonly referred to in the aviation community as the "FLCH trap,"[153] and it was the same automation anomaly that both the FAA and EASA had previously identified as an undesirable automation surprise not adequately explained in Boeing's 777 flight manuals.

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[150] The time lag between activation of the FLCH mode and the PF taking manual control of the flight was about 3.5 seconds, a fast response considering the time necessary for the airplane to respond to the new command mode and for human reaction time to the interruption of vertical profile. *See* Federal Aviation Administration, *Airplane Flying Handbook*, FAA-H-8083-3A at 16-5 (2004) (stating that a "typical" pilot reaction time to an event such as an engine failure is four seconds), *available at* <http://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/airplane_handbook/>.

[151] *See* FCTM § 1.35 ("When the automation systems do not perform as expected, the pilot should reduce the level of automation until proper control of path and performance is achieved.") (as quoted in Hr'g Ex. 2-A, Operations Group Factual Report at 39).

[152] *See* Hr'g Tr. at 180:23-181:5, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[153] *See, e.g.*, Appendix A, Ex. 7, John Croft, *Aviation Week*, "Murky Mode: Boeing Defends Design Philosophy for 777 Autothrust Mode," Dec. 16, 2013; John Croft & Guy Norris, *Aviation Week*, "Were Asiana Pilots Caught in the FLCH 'Trap'?" July 22, 2013, *available at* <http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_07_22_2013_p25-597816.xml>; Robert Goyer, *Flying Magazine*, "Asiana 214 Crash: Lessons Learned," July 9, 2013, *available at* <http://www.flyingmag.com/blogs/going-direct/asiana-214-crash-lessons-learned>; James Fallows, *The Atlantic*, "Professional Pilots on the San Francisco Crash: On the 'FLCH trap' and other possibilities," July 7, 2013, *available at* <http://www.theatlantic.com/national/archive/2013/07/professional-pilots-on-the-san-francisco-crash/277563/>; Stephen Stock et al., "An Automation Trap for Pilots?" *available at* <http://www.nbcbayarea.com/investigations/An-Automation-Trap-for-Pilots-221875391.html>.

Although this automation anomaly had the potential to surprise, Asiana had trained the PF on this feature of the B777's automation -- and indeed on this precise accident scenario -- during the ground school portion of the PF's B777 transition training course. The PF and other trainee captains were warned that when descending in FLCH mode with the engines in idle, the autothrottle will go into HOLD mode and will not wake up, even when airspeed reaches dangerously low levels.[154] This lesson was explained on two occasions by two different instructor pilots, and in both instances, the instructor pilot referenced a high-energy visual approach to SFO as an example of when this situation might arise. The PF attended the lectures, asked questions specifically about this feature of the automation, and discussed the "anomaly" with his fellow trainee captains after class.[155]

Nonetheless, it appears that the PF did not realize that the autothrottle had stopped providing speed protection on the accident flight. As Captain Arnold's experience showed, the PF's apparent confusion in this regard was not unexpected. Moreover, relevant scholarly literature indicates that pilot awareness of automation modes, particularly during late-phase descent, is a common concern. For instance, a seminal study conducted by Sarter, Wickens, and Mumaw showed that only 50 percent of pilots -- 10 out of 20 in the study -- visually registered an inappropriate mode change, and further that "only 1 of those 10 pilots noticed actually that the annunciation was inappropriate."[156] Dr. Nadine Sarter, an expert on automation and human performance, testified at the hearing that pilots were more susceptible to such unexpected automation mode changes "especially during the late phase of descent."[157]

2.2.2 Monitoring and Go-Arounds

Asiana offers robust monitoring and crosscheck training that exceeds FAA requirements. During interviews with NTSB investigators, Asiana pilots reported that the airline's training incorporates a "special emphasis on monitoring skills," including "monitoring, automation, and situational awareness topics," that is built into the airline's CRM training, Safety Management

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[154] *See* Hr'g Ex. 2-D, Statements of Capt. Kim Je Youl and Capt. Jung Tai Soo, and attachments thereto.

[155] *Id.*

[156] Hr'g Tr. at 144:14-145:4, Statement of Dr. Nadine Sarter, Ph.D., University of Michigan (describing 2007 study); *see also id.* at 201:1-9, Statement of Chairman Deborah A.P. Hersman, NTSB Board of Inquiry (identifying "mode confusion" as one of "the big challenges with automation"); Hr'g Ex. 14-E, FAA and CAST Automation Report (2013) at 238 (noting that "vertical mode confusion, speed/energy issues and/or lateral or vertical deviations were all coded against about 40% of consequential outcomes" during the descent and approach phase of flight).

[157] *Id.* Other studies have also noted an across-the-board susceptibility of pilots to unexpected changes in automation. A recent study summarizes these findings:

> The complexity of modes, interactions across modes, and indirect mode changes create new paths for errors and failures. No longer are modes only selected and activated through deliberate explicit actions. Rather, modes can change as a side effect of other practitioner actions or inputs depending on the system status at the time. The active mode that results may be inappropriate for the context, but detection and recovery can be very difficult.

Woods, Sarter, et al., "Behind Human Error" at 182 (2012).

System ("SMS"), and simulator profiles.[158] Additionally, the record further shows that the accident flight crew members received specific monitoring training and feedback in the months just prior to the accident. For instance, the PM received dedicated monitoring training during the CRM portion of his flight instructor training course. And a flight instructor who accompanied the PF on several legs of his OE training flights recalled that he "emphasized crosschecking and monitoring" to the PF during a post-flight debriefing and recommended that the PF "continue monitoring flight instruments and callout changes."[159] The instructor pilot explained that these comments were not motivated by any mistake on the part of the PF during the OE flight, but rather by a broader recognition that monitoring was "very critical" and worth emphasizing.[160] Likewise, the PM received dedicated monitoring training during the CRM session of his instructor training in the months preceding the accident flight.

Studies have shown that humans can be poor monitors, especially when the items being monitored rarely fail or during periods of high workload. Indeed, effective monitoring by flight crews is an issue affecting all operators. In the recent accident involving UPS Flight 1354, for example, it appears that the flight crew did not monitor the airplane's altitude while attempting a localizer approach to a visual landing.[161] Also recently, a Southwest airline crew landed at the wrong airport, an event that likely could have been avoided had they effectively monitored the airplane's instrumentation.[162] The record shows that the members of the accident flight crew, like the other Asiana pilots interviewed, also were well-trained on the stabilized approach criteria and go-around policy.[163] The PM gave a detailed description of the Asiana stabilized approach criteria and go-around policy during his interview with NTSB investigators, and he correctly

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[158] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 92, Interview of Capt. Yim Moon Sik, Asiana Lead CRM Instructor; *see also, e.g.*, *id.* at 65, Interview with F.O. Han Ka Ram, Asiana B777 First Officer, (confirming "a special emphasis on monitoring and staying engaged with monitoring as the PM"); *id.* at 53, Interview of Capt. Park Il Jae, Asiana VP of Safety and Security (stating that Asiana's SMS program includes "components addressing hazard identification, risk management, feedback, and monitoring").

[159] *See id.* at 84, 85, Interview of Capt. Park Ho Yeoul, Asiana B777 Captain.

[160] *See id.* at 84.

[161] *See* NTSB Accident Docket for Crash of UPS Flight 1354, August 14, 2013, Public Hr'g Ex. 2-A, UPS Operations Group Factual Report at 12 (noting that the accident flight triggered the Enhanced Ground Proximity Warning System aural "sink rate" alert at approximately 235 feet, at which point the plane was descending at an excessive rate of 1,536 feet per minute).

[162] *See* Ashley Fantz & Ed Payne, "Question: How could a passenger jet land at the wrong airport? Answer: Uh…," CNN.com (Jan. 13, 2014, 8:34 PM) (noting that "the instrument reading during an instrument landing would have indicated to the pilots they were descending to the wrong location"), *available at* <http://www.cnn.com/2014/01/13/travel/southwest-plane-wrong-airport/>.

[163] *See, e.g.*, Hr'g Ex. 2-B, NTSB Interview Summaries at 65, Interview of F.O. Han Ka Ram, Asiana B777 First Officer (confirming that "either pilot could decide that a go around was necessary"); *id.* at 59, Interview of F.O. Kim Young Chae, Asiana B777 First Officer (stating that in a potentially dangerous approach, he would "say loudly 'Go around!'" and "take control [of the aircraft] if the captain did not go around"); *id.* at 78, Interview of Capt. Oh Cheol Woo, Asiana B777 Captain ("[The B777 captain] further stated that in a dangerous situation, if safety was compromised, that anybody could make a go around. He was asked if this situation was discussed in CRM training and responded yes.").

explained that any captain or first officer can call for a go-around if an approach becomes unstable.[164] The PF also correctly stated that "Asiana had a policy [of] encouraging junior pilots to speak up if they felt uncomfortable about something," and that "if he felt there was something unsafe going on during the flight he could bring that to the PM's attention."[165] In sum, the record demonstrates that both the PF and PM were well-trained on Asiana's stabilized approach criteria and go-around policy.

On the accident flight, the flight crew called the approach stable at 500 feet. At that time, the crew saw the plane was on course and on glide path.[166] Additionally, the airspeed was 135 knots, two knots slower than reference speed, but well within Asiana's stabilized range. As the airplane had needed to slow down, the PF would not have been surprised that the throttles were at idle for the descent.

As the airplane descended below 500 feet, however, evidence of problems arose. The throttles remained at idle during this time, inappropriate for this stage of the approach. Between 500 feet and 200 feet, an elapsed time of approximately 17 seconds, the airspeed fell from 135 knots to 118 knots. Around 200 feet, about 18 seconds before impact, the PM saw four red PAPIs and called out that the airplane was too low. Company procedures call for a mandatory go-around when four red PAPIs are observed, but the flight continued while the crew apparently pitched up to recapture the glide path, which indicated that they believed the autopilot system would maintain speed and provide additional thrust to climb back to the correct glide path. Around 120 feet and just 11 seconds before impact, a quadruple chime sounded in the cockpit, and within just a few seconds, the PM pushed the throttles forward to initiate a go-around.

Adherence to Asiana training and procedures would have required the flight crew to closely monitor airspeed and other primary flight parameters and to execute a go-around as soon as the approach became unstable. Given the pilots' experience and training, there are no obvious explanations for why they did not recognize the deteriorating airspeed and abandon the approach sooner.

One potential explanation concerns "the ineffectiveness of cuing by absence," a theory which Dr. Sarter explained during the NTSB public hearing:

> Let's have a pilot who expects that the throttle will not move but the throttle moves. That is very likely to capture their attention. However, if the situation is the other way around and it's the absence of the movement that they should detect, that is usually something that is much less effective.[167]

On the accident flight, the loss of airspeed below 500 feet was caused not by a change in aircraft behavior, but rather by *a lack of change* of aircraft behavior -- namely, the failure of the throttles

[164] *See id.* at 17-18, Interview of Capt. Lee Jung Min (PM).

[165] *See id.* at 33, 26, Interview of Capt. Lee Kang Kuk (PF).

[166] *See* IIC Opening Presentation at 9.

[167] *See* Hr'g Tr. at 212:8-17, Statement of Dr. Nadine Sarter, Ph.D., University of Michigan.

to advance as expected to maintain commanded airspeed. According to Dr. Sarter, research shows that humans are much less effective at identifying these types of non-events.[168]

A second possibility centers on workload and time constraints. Pilots in a high workload situation have a limited capacity to process information and must use professional judgment to decide what factors should have the highest priority for their attention. As a result, pilots may not focus sufficiently on factors such as airspeed, which should be controlled by the aircraft's automation systems under normal circumstances.[169]

Another potential explanation for the crew's failure to maintain airspeed involves pilot fatigue. There is no specific evidence that fatigue played a role in the accident, as the pilots reported normal sleeping patterns in the days leading up to the flight, and the PF and PM both slept for several hours during the cruise portion of the flight while a relief captain was at the controls.[170] Asiana also took the precaution of assigning a third pilot to the cockpit jumpseat during the approach to provide additional monitoring support for the final portion of the long-haul flight. That said, the record also contains facts that may be suggestive of pilot fatigue. For instance, the PF arrived at Incheon Airport several hours early on the day of the flight,[171] and the CVR indicates that the pilots had an exchange about "long hours working" during the descent into SFO.[172] Additionally, the accident took place during the so-called Window of Circadian Low, the period in the circadian body clock cycle when, according to research, "people generally feel most sleepy and are least able to perform mental and physical tasks."[173] Ultimately, it is well-understood that pilot fatigue can contribute to accidents, especially where, as here, the pilots are confronted with tight time constraints.[174] Consequently, although there is no specific evidence that fatigue played a role in the accident, it cannot be ruled out as a possibility.

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[168] *Id.* at 212:10-12. This concept is especially relevant to high energy approaches, during which the autothrottles typically remain in the idle position throughout most of the approach, *See* Hr'g Tr. at 213:24-214:18, Statement of Capt. David McKenney, International Federation of Airline Pilots' Association ("IFALPA") Human Factors Chairman ("[R]ight now, with the coming in high and fast on approaches, the throttles are always, almost always at idle until the last minute. And it's one of my concerns that I'd like to bring out because we have to look at what the unintended consequences of that are.").

[169] *See id.* at 171:18-173:19, Statement of Capt. David McKenney, IFALPA Human Factors Chairman; *id.* at 170:17-171:17, Statement of Dr. Nadine Sarter, Ph.D., University of Michigan.

[170] *See* Hr'g Ex. 14-A, Human Performance Group Factual Report at 2-6.

[171] *Id.* at 3.

[172] *See* Hr'g Ex. 12-A, CVR Group Factual Report at 12-22.

[173] International Civil Aviation Organization, *Fatigue Risk Management Systems Manual for Regulators* at 2-11 (2012), *available at* < http://www.icao.int/safety/fatiguemanagement/frms%20tools/doc%209966%20-%20frms%20manual%20for%20regulators.pdf>.

[174] *See, e.g.*, NTSB Accident Report, *Runway Overrun During Landing, American Airlines Flight 1420* at 143 (adopted Oct. 23, 2001), *available at* <http://www.ntsb.gov/doclib/reports/2001/AAR0102.pdf> (noting that "fatigue deteriorates performance on work-paced tasks that are characterized by time pressure and task-dependent sequences of activities, as demonstrated by the flight crew's failure to properly perform routine tasks during the final approach phase of flight"); *see also* NTSB Accident Report, *Loss of Control on Approach, Colgan Air, Inc.* at 106-

2.2.3 Visual Approaches

Asiana pilots receive extensive training on conducting visual approaches and are proficient in performing them. All Asiana B777 pilots, including the members of the accident flight crew, have broad practical experience performing visual approaches dating back to their time flying smaller aircraft to regional airports in Asia.[175] Additionally, both Asiana pilots and third-party flight instructors reported being confident in the ability of Asiana pilots to fly visual approaches without difficulty.[176] The training records of the flight crew members support the assessments of the instructors. The PF's training records, for instance, show that he performed a visual approach six times during the simulator stage of his transition training in 2013 and received the highest possible grade on each occasion.[177] Likewise, the PM was asked to perform a visual approach three times during the simulator stage of his instructor pilot training in 2013, and he also received the highest possible grade each time.[178]

Despite substantial evidence showing that the accident pilots were well prepared to fly the visual approach to SFO, members of the media have raised questions about the ability of Asiana pilots to fly visual approaches. In large part, these questions stemmed from the written summary of the PF's interview in the immediate aftermath of the accident, in which it was reported that the PF stated that he found the visual approach to SFO to be "stressful."[179]

For several reasons, however, the written report of the PF's interview appears to be misleading in this respect. First, elsewhere in the interview, the PF reported that he felt well-prepared to perform the SFO approach and that it was "nothing special" and "a general thing for [Asiana pilots]."[180] Second, the PF has since clarified that he misused the English word "stressful," which he mistakenly believed at the time referred to "situations involving the state of being alert and attentive" rather than "anxious or worried."[181] The PF's confusion about the meaning of the word "stressful" comes out clearly elsewhere in his interview. For example, he used the word "stressful" to describe a state of being alert and attentive when he described Asiana instructor pilots, saying: "Normally the instructor pilots are very alert, there is something how can I say, very alertive. Sometimes too much stressful, but he was very natural. Can say it

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07 (adopted Feb. 2, 2010) (hereinafter "Colgan Air Report") , *available at* <http://www.ntsb.gov/doclib/reports/2010/AAR1001.pdf> (observing that in cases of pilot fatigue, "breakdowns in vigilance can occur, response time can slow and become inaccurate, decision-making and risk assessment can degrade").

[175] *See* Hr'g Tr. at 108:6-12, Statement of Capt. Lee Sung Kil, Asiana B777 Chief Pilot; *see also* Hr'g Ex. 2-B, NTSB Interview Summaries at 46, Interview of Capt. Lee Sung Kil, Asiana B777 Chief Pilot.

[176] *See supra* Section 1.4.5.

[177] *See* Hr'g Ex. 2-T, PF's B777 Simulator Training Record.

[178] *See* Hr'g Ex. 2-U, PM's B777 Simulator Training Record.

[179] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 21-40, Interview of Capt. Lee Kang Kuk (PF).

[180] *See id.* at 23.

[181] *See* Appendix A, Ex. 8, Statement of Capt. Lee Kang Kuk (PF) (Mar. 12, 2014).

like that way."[182] None of this is surprising, given that the interview was conducted in English, a language in which the PF is proficient but not fluent.[183] Beyond that, the circumstances surrounding the interview were extraordinarily challenging. Not only had the PF just survived a plane crash in which three people died and many were injured, but he himself was suffering from serious, untreated injuries; at the time of the interview, he had a fractured rib and sprains of the cervical and lumbar regions of his spine, for which he was hospitalized for more than a week upon his return to South Korea.[184]

Asiana made a formal request to listen to the recording of the PF's interview in order to evaluate the context of the PF's statements.[185] However, the NTSB informed Asiana that investigative staff purposely destroyed the recording and that it "no longer exists."[186]

Recorded flight data do not indicate any stress or concern on the part of the PF or the PM -- both of whom had flown successfully into San Francisco dozens of times. Approximately two hours before the scheduled landing, the pilots noted that the glideslope would not be available and discussed routine operational issues concerning the approach and landing, and the CVR reveals no hint of concern among the flight crew about performing a visual approach.[187] Moreover, although the plane was high and fast early in the approach due to tight vectoring by ATC, the crew manually navigated the visual approach such that the aircraft was on glide path and on speed by 500 feet.[188] In short, the accident crew was properly flying a visual approach to that point and would have continued to do so but for the deterioration in airspeed. Whatever problems the flight crew encountered during the final phase of descent, they did not stem from the fact that the flight required a visual approach.

2.3 Automation Surprise and the "FLCH Trap"

The B777's autothrottle system provides stall protection and ensures that the aircraft maintains a safe airspeed in almost all situations. As discussed above, however, this seemingly comprehensive airspeed protection is subject to a narrow exception during which the autothrottle is deactivated and will not wake up. Specifically, when the aircraft is descending in FLCH mode and the throttles are moved to the aft stop position -- either by the pilot or the autothrottle system itself -- the autothrottle setting will automatically and without pilot intervention change to HOLD, thereby disabling airspeed protection. This feature of the automation -- described

[182] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 32, Interview of Capt. Lee Kang Kuk (PF).

[183] *See* Appendix A, Ex. 9, Pilot License of Capt. Lee Kang Kuk (PF) at *2 (indicating that the PF has attained an ICAO English-language proficiency rating of Level 4, on a six-level scale).

[184] *See* Survival Factors Addendum at 2, Attach. 1 at 21; *see also* Appendix A, Ex. 1, Flight Crew Medical Records at *2.

[185] *See* Appendix B, Asiana Correspondence with NTSB, Email from D. Suleiman to D. Tochen (Dec. 23, 2013); Letter from D. Suleiman to D. Tochen (Jan. 9, 2014).

[186] *See* Appendix B, Asiana Correspondence with NTSB, Letter from D. Tochen to D. Suleiman (Jan. 13, 2014); *see also* Letter from D. Suleiman to D. Tochen (Feb. 6, 2014); Letter from D. Tochen to D. Suleiman (Feb. 26, 2014).

[187] *See* Hr'g Ex. 12-A, CVR Group Factual Report at 12-5.

[188] *See* IIC Opening Presentation at 9.

variously as an "anomaly,"[189] "trap,"[190] "inconsistency,"[191] or "surprise"[192] -- was a significant contributing factor in this accident.

2.3.1 Automation Surprise

During the approach to SFO, when the PF manually reduced the throttles to idle following the brief activation of the FLCH pitch mode, the autothrottle automatically entered HOLD mode without any pilot intervention. While no member of the flight crew turned off the autothrottle, the activation of HOLD mode meant that the autothrottles were effectively off, providing no service to the pilots or aircraft. Unbeknownst to the crew, they had fallen into what is known in the industry as the "FLCH trap": when a plane is descending in FLCH mode, if the throttle levers are moved to the idle position, the autothrottle will automatically enter into HOLD mode. In HOLD mode, the autothrottle system ceases to provide any throttle inputs, and the throttles will not move from their last position. As a result, the autothrottle will not wake up to provide stall protection, even when the plane slows well below the commanded speed.

The PF believed the autothrottle was engaged and would hold the command airspeed through the final approach. The other members of the flight crew also expected the autothrottle to function through the final approach, as indicated by their actions in the flight's final minutes.[193] For instance, shortly after the autopilot was disengaged, the FO asked the PM to set the command airspeed to 137 knots -- the approach speed -- suggesting that the flight crew believed the autothrottle system would maintain the command speed. However, because the autothrottle had automatically entered HOLD mode following the engagement of FLCH, the autothrottle system did not provide speed protection, and the plane's airspeed decreased rapidly after the 500 feet stabilization check.

From a pilot's perspective, there are several reasons that an automatic autothrottle change to HOLD mode would be a surprise. *First*, this change compromises one of the most critical safety protections provided by the automation system -- stall protection support. In all other situations, the B777's autothrottle system supports stall protection and ensures that the aircraft maintains a safe airspeed (even in some portions of the flight envelope where it wakes up without pilot command).

Second, the cockpit alerting provided to the pilot when the autothrottle system enters HOLD mode does not reflect the potential seriousness of this mode change. Activation of HOLD mode has the same effect as an autothrottle disconnect -- they both disable the autothrottle's ability to maintain a commanded airspeed. But an autothrottle disconnect triggers

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[189] Hr'g Ex. 2-D, Statement of Capt. Kim Je Youl.

[190] Appendix A, Ex. 7, John Croft, *Aviation Week*, "Murky Mode: Boeing Defends Design Philosophy for 777 Autothrust Mode," Dec. 16, 2013.

[191] Hr'g Ex. 14-I, EASA Debrief Note at 6.

[192] Hr'g Ex. 2-B, NTSB Interview Summaries at 122, Interview of Capt. Eugene Arnold, FAA Test Pilot.

[193] *See id.* at 4, Interview of F.O. Bong Dong Won (FO) (stating that he "was sure the autothrottle (AT) was on"); *id.* at 13, Interview of Capt. Lee Jung Min (PM) (stating that he "expected [the autothrottle] to work").

a caution alert accompanied by redundant aural and visual alerts,[194] while the autothrottle's change to HOLD mode is signified only by the appearance of the word "HOLD" in green letters on the primary flight display, without any aural alert or advisory message. This green text does not suggest to pilots that something as critical as the disabling of airspeed protection may have occurred. A pilot might reasonably believe that the autothrottle system would protect airspeed throughout the flight envelope and that, if there were exceptions, the airplane would provide an alert comparable to a caution advisory.[195]

2.3.2 Documented Concerns

The crew of flight 214 were not the first pilots to be surprised by a lack of autothrottle support. As mentioned, the so-called FLCH trap has been criticized and cited as a safety issue by regulatory bodies and the aviation press. Most notably, the FAA's B787 lead test pilot, Captain Eugene Arnold, noticed the issue in August 2010 and, concerned for its safety implications, brought it to Boeing's attention. During a test flight on the B787, which has the same automation logic as the B777, Captain Arnold was descending from 10,000 feet to 3,000 feet in FLCH when he had to interrupt the descent because of a traffic avoidance alert. When Captain Arnold manually interrupted the FLCH descent, the autothrottle went into HOLD mode and the airspeed began to decay. He expected that the autothrottle would wake up to prevent him from going below the command airspeed, but it did not. Instead, the "airspeed continued to decrease until it was below the minimum maneuvering speed."[196] Fortunately, Captain Arnold was well above ground, and he had time to react to the surprising function of the automation and recover airspeed. He made clear, however, that the "AT system did not function the way he had expected," and he reasoned that "if it had caught him by surprise, he thought that a line crew would have [the] same uncertainty."[197]

Captain Arnold drafted a Flight Test Response Item Report to document his experience, because he thought the automation behavior was "less than desirable" and could be improved.[198] His report described the surprise as follows:

> When in a descent such as FLCH with autothrottle in THR HOLD mode, and the descent has to be manually interrupted for something such as traffic alert, the autothrottle will stay in THR HOLD mode and <u>will not wake up</u> as it does when you capture the

[194] *See* FCOM § 4.20.10 ("The EICAS caution message AUTOTHROTTLE DISC displays and an aural alert sounds when the autothrottle is manually or automatically disconnected.").

[195] Indeed, given their effect on flight operations, one could argue that a switch to HOLD mode should be accompanied by an even stronger warning than that provided for an autothrottle disconnect: The autothrottle remains armed after being disconnected and will automatically wake-up if airspeed reaches the amber band, whereas the autothrottle will not wake up from HOLD mode no matter how much the speed decreases. *See* FCOM § 4.10.20.

[196] Hr'g Ex. 14-A, Human Performance Group Factual Report at 16-17.

[197] Hr'g Ex. 2-B, NTSB Interview Summaries at 122, Interview of Capt. Eugene Arnold, FAA Test Pilot.

[198] *Id.* at 119; *see also* Appendix A, Ex. 6, FAA Response Item Report No. 12.

> original altitude. <u>The speed will decrease well past maneuvering speed</u>.[199]

Captain Arnold's Response Item Report shows that he discussed his concerns about this safety issue with Boeing in a series of emails and conversations.[200] Significantly, the final Response Item Report concluded with the following recommendation from the FAA to Boeing: "The FAA strongly encourages Boeing to implement an FMCS enhance in some future [FMCS] software release that would allow autothrottle wake up during large excursions from target speed."[201] As the accident of flight 214 demonstrates, Boeing did not heed this recommendation.

Like Captain Arnold, EASA separately expressed concern about this "inconsistency in the automation behavior of the airplane." Following testing in May 2011, EASA issued Major Recommendation for Improvement #3, in which it stated:

> Unfortunately there are on the B787 (as well as some other previous Boeing models) <u>at least two automation modes (FLCH in descent and VNAV speed in descent, with ATHR on HOLD) for which the "Autothrottle Wake up" function is not operative and therefore does not protect the aircraft</u>. Although the certification team accepts that this "Autothrottle wake up" feature is not required per certification requirements, <u>these two exceptions look from a pilot's perspective as an inconsistency in the automation behaviour of the airplane. Inconsistency in automation behaviour has been in the past a strong contributor to aviation accidents. The manufacturer would enhance the safety of the product by avoiding exceptions in the "Autothrottle wake up" mode condition</u>.[202]

2.3.3 Lack of Meaningful Guidance

Exacerbating the danger posed by the FLCH trap is the absence in the Boeing manuals of a meaningful explanation of this feature of the automation. Boeing's 777 FCOM and FCTM, the principal sources of guidance for commercial air carriers and their pilots, repeatedly state that the autothrottle system provides comprehensive airspeed control and stall protection:

- *FCOM § 4.20.8:* "The autothrottle system provides thrust control from takeoff through landing."

[199] Hr'g Ex. 2-B, NTSB Interview Summaries at 119, Interview of Capt. Eugene Arnold, FAA Test Pilot (emphases added).

[200] *Id.*; *see also* Appendix A, Ex. 6, FAA Response Item Report No. 12 at 2-3.

[201] Appendix A, Ex. 6, FAA Response Item Report No. 12 at 3.

[202] Hr'g Ex. 14-I, EASA Debrief Note at 6 (emphases added).

- *FCOM § 4.20.9:* "The autothrottle can support stall protection when armed and not activated. If speed decreases to near stick shaker activation, the autothrottle automatically activates in the appropriate mode (SPD or THR REF) and advances thrust to maintain minimum maneuvering speed (approximately the top of the amber band) or the speed set in the mode control speed window, whichever is greater."

- *FCOM § 4.20.13:* "The autothrottle adjusts thrust quickly when airspeed decreases below command speed."

- *FCTM § 7.11:* "When the speed decreases approximately half way through the amber band, the AIRSPEED LOW caution message appears. The autothrottle wakes up, automatically engages in the SPD mode, and returns the airplane to the minimum maneuver speed."

Meanwhile, in contrast to these recurring references, the two manuals together contain just one single-sentence note that can be read to suggest that autothrottle will not support speed protection when in FLCH mode. The note, in its entirety, reads: "When the pitch mode is FLCH or TOGA, or the airplane is below 400 feet above the airport on takeoff, or below 100 feet radio altitude on approach, the autothrottle will not automatically activate."[203]

The contrast between the repeated declarations of stall protection excerpted above and this lone note is striking. Quite clearly, Boeing's manuals run the risk of creating a misleading impression about the scope of protection afforded by the autothrottle following the selection of FLCH mode. Member Sumwalt highlighted this point at the public hearing. After reading aloud the text of FCTM § 7.11, he addressed Captain Darren Gulbransen of Boeing: "Just reading this, it would indicate that the throttles do have the ability to wake up. Where does it caution that if you're in a flight level change mode and the autothrust is in hold, that [the throttles] will not wake up as we've just described here?"[204] Captain Gulbransen could not identify any such explanation in the FCTM, and instead cited the one-sentence note in the FCOM at § 4.20.9. Member Sumwalt then observed: "See, if you know all of those nuances, it's pretty clear, <u>but here we are training people and we're instilling in them that the autothrottle is going to wake up</u>."[205]

The record also indicates that Boeing resisted revising the language of its manuals after such changes were recommended by regulators. Following the issuance of his report noting the "safety issue"[206] presented by the FLCH trap, the FAA's Captain Arnold required Boeing to

[203] *See* FCOM § 4.20.9.

[204] Hr'g Tr. at 130:22-131:18, Statement of Member Robert L. Sumwalt, NTSB Board of Inquiry.

[205] *Id.* (emphasis added).

[206] At the public hearing, Mr. Boyd claimed that "the fact that the autothrottle did not wake up was not a safety issue." Hr'g Tr. at 46:1-2, Statement of Mr. Stephen Boyd, FAA Acting Assistant Manager, Transport Airplane Directorate. However, Captain Arnold clearly believed that this inconsistency in the autothrottle did present a safety issue. *See, e.g.*, Hr'g Ex. 2-B, NTSB Interview Summaries at 121-22, Interview of Capt. Eugene Arnold, FAA Test Pilot ("[Captain Arnold] said that the safety issue was that the AT system did not function the way he had expected

insert a longer and more detailed note in its B787 Airplane Flight Manual ("AFM") in order to provide a clearer explanation of the autothrottle's lack of airspeed protection when in HOLD mode during descent in FLCH.[207] Captain Arnold also recommended that Boeing include this same longer note in the B777 AFM and FCOM. Boeing, however, resisted the recommendation and made no modification to its B777 manuals. Captain Arnold explained that "Boeing and the FAA 'went back and forth'" over the language of the new explanatory note, and that Boeing did not agree to put the new note in its FCOM even though "it would have been desir[able]" to do so.[208]

At the public hearing, Boeing witnesses were questioned several times about the manufacturer's decision not to revise the B777 manuals as recommended by Captain Arnold. In response, a Boeing witness stated on at least three occasions that there was no need to include Captain Arnold's explanation in the B777 manuals because the FCOM already contained "equivalent" language:

> MR. MYERS: In the 787, [the note is] added to the Airplane Flight Manual. In the case of the 777, there was already equivalent language in the Flight Crew Ops Manual, so we didn't need to make any changes there.[209]
>
> ***
>
> MR. MYERS: The words that were added to the airplane flight manual for the 787, the equivalent words are already in the 777 Flight Crew Operating Manual, the FCOM, and they have been for at least 15 years. That's as far back as our history could go. So we didn't need to add additional words to the manual. It's already there.[210]
>
> ***
>
> MR. MYERS: In the 777, there has always been the note. . . . [W]e moved it from Chapter 9 to Chapter 4, but it has always been in the manual.[211]

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or assumed it would operate. He thought that if it had caught him by surprise, he thought that a line crew would have [the] same uncertainty about how the system might function.").

[207] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 120, Interview of Capt. Eugene Arnold, FAA Test Pilot. This statement read: "During a descent in FLCH mode or VNAV SPD mode, the AT may activate in HOLD mode. When in HOLD mode, the AT will not wake up even during large deviations from target speed and does not support stall protection."

[208] *Id.* at 121.

[209] Hr'g Tr. at 52:25-53:6, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[210] *Id.* at 54:8-18.

[211] *Id.* at 56:4-14.

As this testimony makes clear, Boeing attempted to dismiss questions about whether it should have modified its B777 FCOM by claiming that "equivalent" language to Captain Arnold's proposed note already was in the B777 manuals. Captain Arnold, however, was very familiar with the existing note in the B777 FCOM, and he did not view that language as "equivalent" to the note that was ultimately inserted into the B787 AFM. Captain Arnold referred to the note in the B777 FCOM as "another, shorter note," and the FAA Response Item Report states that "[t]he note in the FCOM is not as specific as it could be when addressing the concerns raised by the FAA and EASA."[212] Captain Arnold recalled that Boeing had initially proposed to use a version of that shorter note in the B787 AFM, but he had "insisted that the longer note be inserted in the AFM instead."[213] Captain Arnold also explained that the issue raised in Response Item Report had not been fully resolved to his satisfaction because "it would have been desired to also put that statement in the FCOM, but Boeing did not do so."[214]

The following comparison of the two notes illustrates clearly that they are not equivalent:

B777 FCOM:	***B787 AFM:***
When the pitch mode is FLCH or TOGA, or the airplane is below 400 feet above the airport on takeoff, or below 100 feet radio altitude on approach, the autothrottle will not automatically activate.	During a descent in FLCH mode or VNAV SPD mode, the AT may activate in HOLD mode. When in HOLD mode, the AT will not wake up even during large deviations from target speed and does not support stall protection.

*   *   *   *   *

The record indicates that the FLCH trap led to the disabling of the autothrottle and its wake-up feature in this accident, that Boeing was well aware of this anomaly prior to the accident, and that Boeing refused to adequately address it in its manuals.

2.4 Insufficient Airspeed Alert

Another factor contributing to the accident was the inadequacy of the B777 low airspeed alerting system. In addition to visual cues about airspeed on the primary flight display, the B777 is designed to provide pilots with an aural alert in the event of an impending low-speed condition.[215] The B777's three levels of alerts are warnings, cautions, and advisories, and the low airspeed alert falls into the middle category of "cautions." Caution alerts are signified by yellow or amber lights and, according to Boeing, "require immediate crew awareness but do not

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[212] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 120, Interview of Capt. Eugene Arnold, FAA Test Pilot; *see also* Appendix A, Ex. 6, FAA Response Item Report No. 12 at 3.

[213] *See* Hr'g Ex. 2-B, NTSB Interview Summaries at 120, Interview of Capt. Eugene Arnold, FAA Test Pilot.

[214] *See id.* at 121.

[215] Hr'g Ex. 14-C, B777 FCOM Description of Low Speed Alert System.

necessarily require immediate crew action."[216] By comparison, "warnings" are signified by red lights and require immediate crew action.

At the public hearing, Boeing's Robert Myers explained that the low airspeed alert was a "caution" rather than a "warning" because "the original scenario for which we designed the alert was a cruise condition, and so in that case, often there is much more time before the pilot must take action."[217] In other words, the airspeed alert was designed to prompt pilot awareness -- not necessarily immediate pilot action -- because it was intended for use at cruise altitudes when pilots have more time to recover. But as the FAA's Aviation Rulemaking Advisory Committee warned in March 2013, "[d]epending on the phase of flight, there may be a need to re-categorize certain alerts from a lower urgency level to a higher urgency level."[218] An aircraft experiencing a low speed situation on final approach, such as Asiana flight 214, does not have the luxury of time to recover, and the crew must take immediate action to save the flight. Given this reality, Boeing's classification of the low airspeed alert as a "caution," which "does not necessarily require immediate action," may be inappropriate, especially in the context of a descent or final approach.[219]

But whether classified as a "caution" or a "warning," the investigative record points to an even more fundamental problem with Boeing's low airspeed alert: namely, that it failed to enunciate in time to allow the flight crew an opportunity to correct the developing low speed situation and avoid an accident. At the hearing, Boeing representatives were questioned closely about whether the low airspeed alert provides sufficient warning during the descent and approach phases of flight. Mr. Myers defended the design, stating:

> [T]he original scenario for which we designed the alert was a cruise condition, and so in that case, often there is much more time before the pilot must take an action. In the case of being on final approach, as in the accident scenario, <u>we built in still some reaction time for the crews, and the reaction time in this case falls well within the range that we designed the alert for</u>.[220]

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[216] Hr'g Tr. at 40:4-22, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[217] *Id.* at 50:16-20, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[218] FAA Aviation Rulemaking Advisory Committee Recommendation, Avionics System Harmonization Working Group, *Low Airspeed Alerting Phase 2 Task* at 13, Mar. 11, 2013, *available at* < http://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/TAE.T5.Phase2.CoverLetter.and.RecommendationReport03122013.pdf>.

[219] Boeing's use of a "master caution" chime for the low airspeed warning is also problematic. As mentioned, the master caution chime that sounds when airspeed is too low is identical to the master caution chime that sounds in response to more than 70 other problems on the aircraft. Boeing representatives stated at the public hearing that they had considered adopting a more unique or salient aural warning for a low speed condition, but ultimately had declined to do so. *See* Hr'g Tr. at 58:18-59:2, 69:21-23, Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

[220] *Id.* at 50:18-23 (emphasis added), Statement of Mr. Robert Myers, Boeing Chief Engineer of Flight Deck Engineering.

Data from the NTSB's independent investigation contradicts this claim. As explained above, the NTSB's simulator testing concluded that the last moment at which the flight crew could have successfully initiated a go-around was 12 seconds prior to impact.[221] Meanwhile, the CVR shows that the low airspeed caution did not alert until 11 seconds prior to impact, by which point the airspeed was approximately 114 knots, 23 knots below reference speed.[222] Had the alert sounded sooner, the pilots could have reacted in time to go around and execute an uneventful landing. Even though the flight crew responded swiftly and the throttles were fully advanced within approximately three seconds of the alert sounding,[223] the alert did not enunciate in time to permit the flight crew to avert an accident.

For more than a decade, the NTSB has repeatedly warned of the need to improve existing low airspeed alert systems.[224] In particular, the agency has emphasized the necessity of a redundant aural alert, in addition to visual alerts, to allow for a "timely response from the pilots before the onset of stick shaker."[225] On the accident flight, however, the aircraft did not provide an aural indication of low airspeed until it was too late. In other words, even though the B777 is equipped with a redundant aural alert, the alert failed to serve its intended purpose, as it did not warn the flight crew of the impending low airspeed situation in time to permit a "timely response from the pilots."

2.5 High Workload Approach

On the accident flight, a number of factors conspired to make the final approach one of extraordinarily high workload -- the unique and challenging features of SFO airport, demanding speed and altitude restrictions issued by ATC, and the control tower's delay in responding to the flight crew and issuing a landing clearance. The confluence of these factors and the resulting pilot workload during the final moments of the flight left the crew of flight 214 particularly

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[221] Aircraft Performance Group Study Addendum at 14 (identifying 12 seconds prior to impact as the last time at which a "normal go-around [was] still possible").

[222] Hr'g Ex. 12-A, CVR Group Factual Report at 12-37; Hr'g Ex. 13-B, Aircraft Performance Group Study at 14.

[223] *See* Federal Aviation Administration, *Airplane Flying Handbook*, FAA-H-8083-3A at 16-5 (2004) (stating that a "typical" pilot reaction time to an event such as an engine failure is four seconds), *available at* <http://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/airplane_handbook/>; *see also* NTSB Investigative Hearing: UPS Flight 1354, Statement of Dr. Tom Chidester, FAA CAMI Acting Deputy Director (opining that a margin of 2.4 seconds was "not much time for people to react and respond").

[224] *See* NTSB Accident Report, *Loss of Control and Impact with Terrain, Aviation Charter, Inc.*, at 60 (adopted Nov. 18, 2003), *available at* <https://www.ntsb.gov/doclib/reports/2003/AAR0303.pdf> (observing that "existing stall warnings are inadequate to reliably prevent hazardous low-airspeed situations" and issuing Safety Recommendations A-03-53 and -54 to the FAA recommending the establishment of new requirements for low airspeed alert systems); *see also* Colgan Air Report at 95 ("During the almost 6 years since the NTSB issued Safety Recommendations A-03-53 and -54, . . . accidents and incidents involving a lack of flight crew awareness of decreasing airspeed have continued, indicating that existing stall warnings are not a reliable method for preventing inadvertent hazardous low-speed conditions.").

[225] Colgan Air Report at 96, 98; *see also id.* at 98 ("[T]he NTSB recommends that . . . the FAA require the installation of low-airspeed alert systems that provide pilots with redundant aural and visual warnings of an impending hazardous low-speed condition.").

susceptible to automation surprise and mode confusion. As such, the heavy pilot workload was a contributory factor in this accident.

To some extent, higher pilot workload is inherent in an approach to SFO because of the unique circumstances and challenges the airport presents to pilots.[226] As Captain David McKenney, Co-Chair of the Performance-based Operations Aviation Rulemaking Committee, explained at the public hearing, these challenges are particularly acute when performing a visual approach to runway 28L.[227] First, the approach to SFO is "usually high and fast" due to terrain, traffic, and noise abatement procedures.[228] Second, the space between parallel Runways 28L and 28R -- just 750 feet -- is "very narrow compared to most airports."[229] Captain McKenney explained that the proximity of the runways "distracts the coordination between the crew" because "you're actually trying to find the other airplanes" during final approach.[230] This task is made more difficult by the fact that SFO is a high traffic airport.[231] The accident flight had to contend with significant air traffic, as the tower warned the flight crew earlier in the approach that "there's traffic behind and to the right that does have you in sight."[232] The combination of these factors means that, even under the best conditions, a visual approach to runway 28L is "very complicated."[233] Consistent with this assessment, media reports indicate that "Lufthansa statistics rank the San Francisco International Airport at the top of the list for aborted landings," and at least one German pilot has stated that "[a] stabilized arrival in San Francisco has become practically impossible."[234]

Nonetheless, all Asiana pilots are fully equipped to handle complicated approaches, and Asiana flights have made uneventful landings at SFO on a daily basis for more than 20 years. On the accident flight, however, the workload of this already challenging approach was further increased by ATC's requirement that the flight crew adhere to demanding speed and altitude restrictions. ATC required the flight crew to maintain a speed of 210 knots at 4,000 feet and, after clearing the aircraft for visual approach, to maintain 180 knots until just five miles from the

[226] For this reason, the Korean Ministry of Land, Infrastructure and Transportation has designated SFO a "special airport." *See* Hr'g Ex. 2-A, Operations Group Factual Report at 30.

[227] *See* Hr'g Tr. at 174:19-176:20, Statement of Capt. David McKenney, IFALPA Human Factors Chairman.

[228] *Id.* at 175:17-22.

[229] *Id.* at 174:23.

[230] *Id.* at 175:4-20.

[231] *Id.* at 175:12-13 ("[I]f it's the middle of the night, and there's nobody there, that's fine, but normally [the traffic] is there.").

[232] Hr'g Ex. 12-A, CVR Group Factual Report at 12-31.

[233] Hr'g Tr. at 175:17, 176:8-10, Statement of Capt. David McKenney, IFALPA Human Factors Chairman.

[234] Gerald Traufetter, "San Francisco: Crash 'Was Only a Matter of Time,'" *Der Spiegel Online* (July 8, 2013), *available at* < http://www.spiegel.de/international/world/pilots-missing-control-systems-led-to-san-francisco-crash-a-909956.html>.

airport. These instructions set up flight 214 for a high and fast approach, "caused [a] delay in changing to landing flaps configuration," and ultimately "added burden to the flight."[235]

Indeed, when presented with the same high and fast start during the NTSB's simulator testing, experienced FAA and Boeing test pilots struggled to obtain a stabilized approach profile by 500 feet. Out of ten test flights conducted under conditions replicating the accident profile, four were deemed unstable at 500 feet due to excessive sink rates. Additionally, three of the test flights were also deemed unstable due to excessive speed, deviation from glide path, and inappropriate throttle position, respectively. And even on the test runs that were considered stable at 500 feet, the test pilots were forced to exceed Asiana's recommended maximum sink rate earlier in the approach.[236]

The high and fast approach mandated by ATC's instructions also foreclosed the possibility of utilizing the VNAV path pointer to ease pilot workload. In ordinary conditions, the use of the VNAV mode can ease pilot workload during approach. As the simulator testing showed, however, using the VNAV mode actually "<u>increased</u> workload in the high start conditions," and in one test flight even led to a significant airspeed deviation.[237] In written comments regarding that test flight, the experienced FAA test pilot stated:

> [M]y conclusion is, if you're above the path and fast (i.e. 'high and fast'), don't try and fix the problem with VNAV . . . many reasons for that conclusion, including: induces potential for automation confusion and (as evidenced in this particular condition) it doesn't do it particularly well.[238]

Further contributing to the high workload of the approach was the control tower's delayed response to requests for landing clearance. The flight crew attempted to contact the control tower for landing clearance at an altitude of more than 2,000 feet, but the control tower did not respond. After more than a minute of silence from the tower, and after the aircraft had descended through 1,000 feet, flight 214 again attempted communication with the control tower. Eventually, after another eight second delay, the control tower responded, finally issuing a clearance to land. At the time the clearance was issued, the aircraft was already passing through approximately 600 feet and was just 43 seconds from impact.[239] This late landing clearance added to the flight crew's workload by forcing them to accomplish their landing checks under even more demanding time constraints.

At the investigative hearing, Dr. Sarter highlighted the significance of time constraints, noting that "[t]hese kinds of accidents often have a certain signature and one of the factors that

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[235] Hr'g Ex. 2-B, NTSB Interview Summaries at 15, Interview of Capt. Lee Jung Min (PM).

[236] *See* Human Performance Group Factual Report, Addendum 2 at 8.

[237] *Id.* at 9 (emphasis added).

[238] *Id.*

[239] Hr'g Ex. 12-A, CVR Group Factual Report at 12-36; Hr'g Ex. 10-A, FDR Group Factual Report at 10-10 (Figure 2).

tends to play a role is time constraints."[240] Tight time constraints further increase pilot workload, making it more difficult for flight crews to recognize and process all the information presented to them, including flight deck parameters and external visual cues during the late phase of descent. As Dr. Sarter explained, the risk of data overload is especially pronounced during final approach when pilots "have to deal and cope with all of these demands under very high time constraints."[241] In one widely cited study, for instance, only ten in 20 test pilots even noticed changes in flight mode annunciations during descent, and among the ten who did notice the mode change, only one pilot actually realized that the wrong mode had been introduced.[242]

Captain McKenney echoed Dr. Sarter's comments, offering similar observations regarding the negative impact of high workload and tight time constraints on pilot monitoring:

> [D]uring times of high workload, which . . . is usually a result of those unexpected changes and during a complex arrival or with distractions, there's a myriad of tasks that we have to do as pilots, and . . . you're doing so many things that at some point, you can't do everything that's required of you.[243]

The result, he explained, is that pilots are forced to perform a sort of "risk management" calculus, in which they focus on the tasks that demand their immediate attention, and they rely on automation to handle lower-priority tasks.[244] Of course, this in turn makes pilots more susceptible to unsuspected and undesirable automation events.

According to both Dr. Sarter and Captain McKenney, high workload negatively impacts pilot monitoring and makes flight crews more susceptible to automation surprise, especially under tight time constraints. The flight 214 pilots were forced to contend with this exact scenario during the final approach to SFO, and these circumstances played a contributing causal role in the accident.

3. CONCLUSIONS

3.1 Findings

1. The pilots were properly certificated and qualified in accordance with applicable Korean, ICAO, and FAA regulations. The airplane was properly certified, equipped, and maintained in accordance with all applicable regulations.

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[240] Hr'g Tr. at 170:20-22, Statement of Dr. Nadine Sarter, Ph.D., University of Michigan.

[241] *Id.* at 171:14-17.

[242] *Id.* at 144:6-145:4.

[243] *Id.* at 172:1-9, Statement of Capt. David McKenney, IFALPA Human Factors Chairman; *see also id.* at 173:3-6 ("[E]ven if you recognize all the alerts and warnings that we have and you respond as quickly as possible and the aircraft responds, it's not enough time.").

[244] *Id.* at 171:18-173:19.

2. There were no material pre-impact structural, engine, or system failures. Weather was not a factor at the time of the accident. There is no specific evidence that any pre-impact physical or medical conditions adversely affected the pilots' performance during the flight, but the possibility of pilot fatigue cannot be ruled out under the circumstances.

3. Asiana maintains a comprehensive training program that meets or exceeds all applicable FAA, Korean, and international standards.

4. Both the PF and PM had received special training on landings at SFO and in performing high-energy visual approaches to runway 28L. The accident pilots also had received extensive CRM training and instruction, including recurrent CRM training courses in March and April 2013.

5. All three pilots received extensive training on conducting visual approaches and have performed numerous visual approaches during their time as line pilots, particularly during flights to regional airports in Japan, Korea, and elsewhere.

6. In April 2013, the PF received specific instruction during a ground school course on the possibility that when in FLCH mode on approach, the autothrottle may automatically switch to HOLD mode, thereby disabling airspeed protection and the autothrottle wake-up function.

7. According to Asiana company policy, any pilot can and should call for a go-around -- without penalty -- whenever confronted with a potential safety issue.

8. San Francisco International Airport is designated as a special airport by the Korean Ministry of Land, Infrastructure, and Transportation due to the challenges it poses to pilots.

9. ATC at SFO often brings planes in high and fast due to terrain, traffic, and noise abatement procedures. The accident flight fit this profile, as ATC instructed Asiana flight 214 to maintain 180 knots until just five miles from the airport.

10. The ILS system for the Runway 28L was inoperative on the day of the accident. ATC provided the flight crew with a visual approach to runway 28L.

11. The SFO control tower failed to respond to the flight crew's initial request for landing clearance, and the tower's delayed response to a second request increased the pilot workload of the approach.

12. At about 1,600 feet, the FLCH pitch mode became engaged for an unknown reason, and the autopilot commanded the plane to climb towards the missed approach altitude of 3,000 feet. Within approximately three seconds, the PF disconnected the autopilot by the switch on the control yoke and moved the throttles to idle.

13. The selection of the FLCH mode and moving the throttles to idle resulted in the autothrottle system engaging in HOLD mode with the engines at idle. While in HOLD mode, the autothrottle and its wake-up function is disabled, and the autothrottle will not protect airspeed.

14. The autothrottle HOLD mode is the functional equivalent of disconnecting the autothrottle system in that it does not maintain the commanded airspeed during manual flight. When autothrottle is disconnected, however, the mode changes to SPD mode and the autothrottle remains armed and will wake up if airspeed decreases into the amber band. In contrast, when the autothrottle is in HOLD mode, it will not wake up even in the event of large deviations in airspeed.

15. An aural alert sounds when the autothrottle is disconnected. No aural alert sounds or advisory message displays when the autothrottle engages in HOLD mode.

16. The flight crew believed that the autothrottle system would maintain the commanded airspeed through the final approach.

17. The Boeing 777 FCOM and FCTM state repeatedly that the autothrottle system will wake up to correct for deviations from target airspeed, but they contain only one oblique reference to the fact the autothrottle system will not maintain airspeed in certain modes, including FLCH.

18. The design and functioning of the B787 autothrottle system is substantially identical to the design and functioning of the B777 autothrottle system.

19. Both the FAA and EASA expressed concern about inconsistencies in the authothrottle functioning of the B787 when in descent in the FLCH pitch mode.

20. The lead FAA test pilot for the B787 recommended that Boeing revise its B787 FCOM to better inform pilots of the functions and limits of the Boeing autothrottle system when descending in FLCH mode; Boeing did not do so.

21. The FAA strongly encouraged Boeing to implement enhancements to the B777's FMCS software that would allow the authothrottle to wake up during large deviations from target speed; Boeing did not do so.

22. Between 1,000 and 500 feet, the FO made several callouts regarding the airplane's sink rate, in accordance with Asiana procedures. The PF acknowledged the FO's callout and the sink rate was quickly reduced.

23. At 500 feet, the airplane was on glide path, on course, and within appropriate airspeed range.

24. The master caution alert signaling low airspeed sounded 11 seconds prior to impact; approximately three seconds later, the PM manually advanced the throttles.

25. The same master caution alert sounds in response to more than 70 conditions on the airplane, one of which is low airspeed. Unlike a “warning” alert, a “caution” alert does not require “immediate crew action.”

26. Simulator testing showed that the latest point on the accident flight at which a “normal go-around [was] still possible” was 12 seconds prior to ground impact. The low airspeed alert, which sounded 11 seconds prior to impact, did not provide the flight crew with sufficient time to regain maneuvering speed and avoid the accident.

27. Simulator recreations of the flight found it impossible to achieve a stabilized profile at 500 feet under the conditions of the accident profile without violating certain policies and procedures of Asiana.

28. The Asiana flight attendants performed heroically and carried out their evacuation duties in an exemplary manner.

3.2 Probable Cause

The probable cause of this accident was the flight crew’s failure to monitor and maintain a minimum safe airspeed during a final approach, resulting in a deviation below the intended glide path and an impact with terrain. Contributing to this failure were (1) inconsistencies in the aircraft’s automation logic, which led the crew to believe that the autothrottle was maintaining the airspeed set by the crew; and (2) autothrottle logic that unexpectedly disabled the aircraft’s minimum airspeed protection.

Significant contributing factors to the accident were (1) inadequate warning systems to alert the flight crew that the autothrottle had (i) stopped maintaining the set airspeed and (ii) stopped providing stall protection support; (2) a low speed alerting system that did not provide adequate time for recovery in an approach-to-landing configuration; (3) the flight crew’s failure to execute a timely go-around when the conditions required it by the company’s procedures and, instead, to continue an unstabilized approach; and (4) air traffic control instructions and procedures that led to an excessive pilot workload during a high-energy final approach.

3.3 Safety Recommendations

1. To the FAA: Require Boeing to insert the following language into the B777 FCOM in Section 4.20.9: “During a descent in FLCH mode or VNAV SPD mode, the AT will activate in HOLD mode if the throttles are reduced to the idle position, either manually by the pilot or by operation of the autothrottle. When in HOLD mode, the AT will not wake up even during large deviations from target speed and does not support stall protection.”

2. To the FAA: Require Boeing to modify low speed alert system on the B777 to provide an aural alert that will provide a margin for conducting a safe go-around, based on normal pilot reaction time, with the engines at idle, and the airplane at a low altitude.

3. To the FAA: Require Boeing to upgrade the low airspeed alert from a “caution” to a “warning,” especially during the final approach phase of flight.

4. To the FAA: Require Boeing to modify the crew altering system on the B777 to provide an aural alert and advisory message of “airspeed protection disabled” when the autothrottle system is engaged in HOLD mode.

5. To the FAA: Require Boeing to provide enhanced training guidance on the lack of airspeed protection when the autothrottle system is in HOLD mode.

6. To the FAA: Require Boeing to modify the autothrottle system on the B777 such that the system reengages from HOLD to the Speed or Thrust mode when the airspeed reaches the top of the amber band shown on the primary flight display.

7. To the FAA: Determine the appropriate level of workload for pilots operating highly automated airplanes when normally used and often relied upon features are not available.

8. To the FAA and Boeing: Develop and implement changes to the design, alerting features, or training guidance for the B777 and those airplanes with related systems, to mitigate automation “surprise” in certain modes that cause the autothrottle wake up function to become inoperative.

9. To Boeing: Develop and implement an improved means of customer reporting to provide feedback on positive and negative automation features from in-service use that the company can use to improve the “human-centered” quality of its automated systems.

10. To ICAO: Develop guidance to member states concerning accident investigation and interviews of surviving crewmembers that: (i) member states should determine whenever possible that the surviving crewmembers have received appropriate medical attention before being interviewed; and (ii) member states should conduct interviews in the native language of the surviving crew members whenever possible.

11. To NTSB: Revise internal evidence-gathering procedures to require NTSB investigators to preserve all audio recordings of investigative interviews until at least the conclusion of the fact-finding phase of the investigation.